Volume 10 Number 4

BULLETIN

of the

American Association *of* Petroleum Geologists

APRIL
1926

RAYMOND C. MOORE
EDITOR

PUBLISHED BY THE ASSOCIATION
CHICAGO, ILLINOIS

THE BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

The Bulletin of the American Association of Petroleum Geologists is published on or about the 15th of each month by the Association, at the University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois.

The subscription price to non-members of the Association is $15.00 per year (separate numbers $1.50) prepaid to addresses in the United States, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Dominican Republic, El Salvador, Bolivia, Colombia, Honduras, Nicaragua, Peru, Hawaiian Islands, Philippine Islands, Guam, Samoan Islands.

Postage is charged extra: For Canada, 40 cents on annual subscriptions (total $15.40), and for all other countries in the Postal Union, 70 cents on annual subscriptions (total $15.70).

Communications for the editor and manuscripts should be addressed to John L. Rich, Ottawa, Kan.

Requests for information concerning special rates to public and university libraries, remittances and business correspondence should be sent to Fritz L. Aurin, Secretary-Treasurer, Ponca City, Okla.

Correspondence regarding advertisements should be addressed to William B. Heroy, Advertising Manager, Room 1500, 45 Nassau Street, New York City.

Claims for non-receipt of preceding numbers of the Bulletin must be sent to the secretary within three months of the date of publication in order to be filled gratis.

The BULLETIN furnishes thirty-five free reprints (without covers). Additional reprints, and covers for all or part, are furnished at cost. **Orders for reprints** should accompany corrected galley proof. **Proofs and communications concerning proofs or reprints** should be addressed to Daisy Winifred Heath, Rosenwald Hall, University of Chicago, Chicago, Ill.

Back numbers of the BULLETIN can be ordered from the secretary at the following rates: Vol. I, $5.00; Vol. II, $4.00; Vol. III, $5.00; Vol. IV, $7.50, separate numbers, each $3.00; Vols. V and VI, each $10.00; Vols. VII and VIII, cloth bound, each $11.50; separate numbers, each $2.00, except Vol. V, No. 2, $3.50; Vol. 9, $15.00, numbers 1, 2, and 3, each $3.00, numbers 4 to 9, inclusive, each $1.50.

Entered as second-class matter November 21, 1925, at the post-office at Chicago, Ill., under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

PRINTED IN THE U.S.A.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

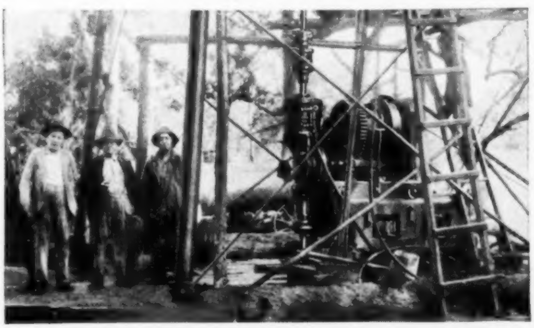
Vol. 10 **APRIL 1926** **No. 4**

CONTENTS

Diamond Drilling Is World-Wide

SULLIVAN DIAMOND CORE DRILLS are in use, or have been used recently for oil field exploration, in fields as widely scattered as Mexico, India, Venezuela, Borneo, Russia, Peru, Algeria, and Portuguese East Africa.

Foreign users employ the diamond core drill because it gives accurate knowledge (cores) of new fields in the quickest time and at the lowest cost; because it FINISHES THE HOLE under difficulties which are impossible to other types, and because it is adaptable to any kind of ground or any depth of hole



Sullivan Diamond Drill Making a Test in Portuguese East Africa

Low cost and ease of transportation, due to light weight and compactness of the outfit, and to the absence of large casings, are important factors.

Sullivan Diamond Core Drills are built in capacities from 500 to 7000 feet in depth. They are fully described in 80-page catalogue No. 4480-O "*Diamond Drilling for Oil.*"

Send for your copy (FREE)

SULLIVAN MACHINERY COMPANY

127 So. Michigan Ave., Chicago

Dallas Garber Tulsa Los Angeles London Santiago Paris
Mexico City Johannesburg Calcutta Sydney Tokyo

Volume 10 Number 4

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL 1926

THE SUBSURFACE GEOLOGY OF THE BIG LAKE OIL FIELD

E. H. SELLARDS AND LEROY T. PATTON[1]

ABSTRACT

The paper is based on the results of the microscopic and mineralogic examination of more than one thousand samples taken from different wells in the field at varying depths from the surface. The results of these examinations were used to correct and supplement drillers' logs and a study was made of the field by use of both classes of data.

The formations are found to belong to the Permian, Triassic, and Cretaceous systems. They are described in detail and a generalized geologic column presented. It is shown that in the majority of cases the oil occurs in an oölitic dolomite, and that in all cases it occurs in strata closely related to this dolomite. The oölitic dolomite is found to have certain definite characteritsics by which it may be identified in dry holes as well as in producing wells, thus furnishing a reliable and easily identifiable key horizon. It is shown that the formations contain large amounts of anhydrite, which occur up to within short distances of the producing horizon, and these deposits of anhydrite are invariably wrongly identified by the drillers as "lime," and mapping of subsurface structure by using the top of the "lime" as shown by the drillers' logs is more or less unreliable, especially in territory where no production is found. The structure of the field as shown by mapping on the oölitic dolomite as identified in well samples is discussed.

The oil field which this paper describes is located in the southwestern part of Reagan County, Texas (Fig. 1). The discovery well in this field is University Well No. 1 of the Big Lake Oil Company (formerly University Well No. 1 of the Texon Oil and Land Com-

[1] Published by permission of the director of the bureau of economic geology of the University of Texas. This paper, read at the March, 1925, meeting of the Association was returned to the authors for adjustment of certain of the illustrations, and owing to an oversight on their part was not submitted for publication until February, 1926. No revision has been undertaken other than in the structure map, which has been added to by including wells drilled to January 1, 1926. Total production to January 1, 1926, is likewise included.

Bureau of Economic Geology, Austin, Texas

pany, and also known as Santa Rita No. 1). This well was brought in on June 5, 1923, with a reported initial production of 80 barrels per day. About a year elapsed between the completion of this well and the completion of a second well, University No. 2, which was

FIG. 1.—Sketch map of Texas, indicating the location of the Big Lake oil field, west of San Angelo.

brought in February 23, 1924. Approximately a year later, March 1, 1925, there were seventeen producing wells in the field with an average daily production for the field of 11,500 barrels. On December 31, 1925, there were 74 producing wells, the production on this day being 32,317 barrels. The average production per well per day for December, 1925, was 440 barrels. The total gross production in the field to January 1, 1926, was 10,060,330 barrels. The depth to production approximates 3,000 feet. The oil is of a gravity approxi-

mating 39 Baumé. The location of wells is shown in a general way on the accompanying sketch map (Fig. 2).

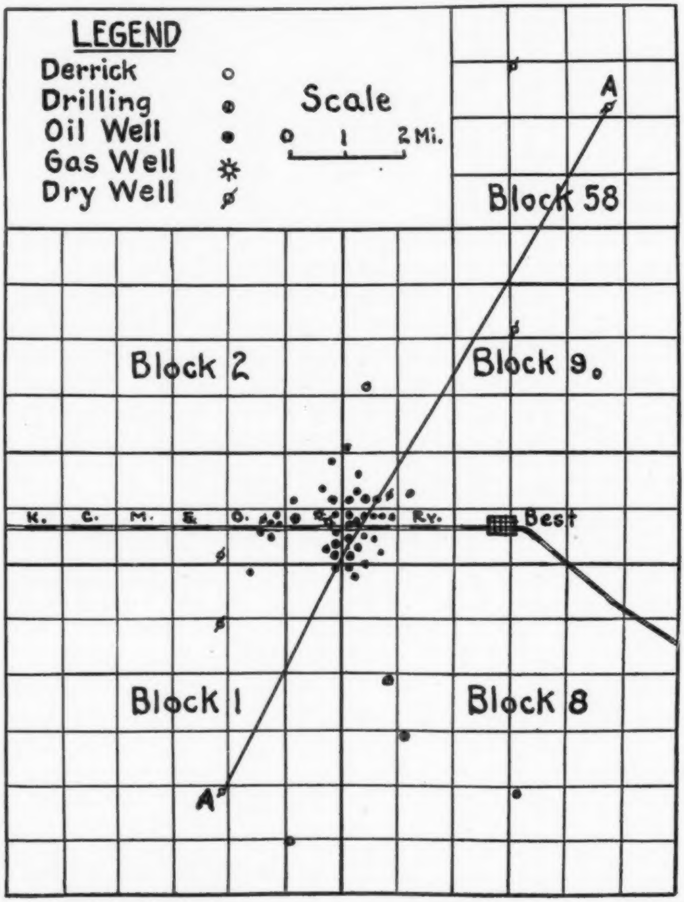


FIG. 2.—Sketch map of the Big Lake oil field and immediately surrounding area. The line AA' indicates the cross-section of Fig. 9.

As this field is located on university land, the bureau of economic geology of the University of Texas established a field laboratory at

Big Lake, Reagan County, August 15, 1924, for the purpose of collecting and studying samples. This laboratory, which was in charge of the writers, was maintained until November 15, 1924, after which time well samples were collected by a representative of the university, and the work of examining samples continued at Austin. Through the courtesy of the Transcontinental Oil Company, the junior author was also permitted to study several hundred additional samples from this field. In all, over one thousand samples from various wells were studied. In addition to these, use has been made of a number of other samples described in the subsurface laboratory of the bureau by other members of the staff. The data thus obtained have been used to correct and supplement drillers' logs.

The writers wish to express their appreciation of the courtesy of the Big Lake Oil Company, the Texon Oil and Land Company, and other operators in the field for furnishing samples and data concerning the field and for permission to use information obtained in connection with the examination of the well samples. Mr. L. G. Graves, petroleum technologist, University of Texas, stationed at Best, Texas, has supplied the data on production.

THE GEOLOGIC SECTION

The geologic section in the Big Lake oil field includes formations of the Comanchean, Triassic, and Permian systems. A graphic representation of the section is given in Figure 3.

THE COMANCHEAN

The Comanchean at this locality consists of from 200 to 400 feet of limestones, including the Georgetown, Edwards, Comanche Peak, and Walnut formations. Underneath these limestones are basement sands varying from 100 to 200 feet in thickness. The average thickness of the Comanchean, as indicated in the generalized section, approximates 500 feet.

A diamond drill core passing through the Cretaceous at a locality about four miles west of the field was examined by Dr. T. W. Stanton who has reported as shown on page 370.

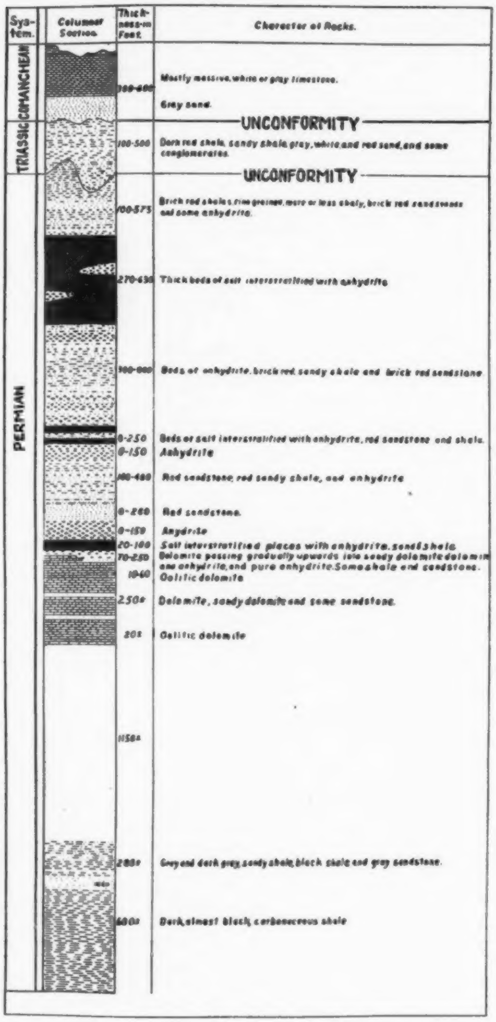


FIG. 3.—Generalized section in the Big Lake oil field. Scale: 1 inch = 1,000 feet

Fossils from diamond drill core from the Texon Oil and Land Company well on Section 6, Block 2, southwest Reagan County, Texas, collected by W. B. Lang, 1923, including a few specimens collected by T. W. Stanton.

Depth in Feet	Fossils observed
40 to 50	*Ostrea* or *Gryphaea* sp., small specimens. *Protocardia* sp., large fragment.
50 to 60	*Ostrea* sp.; *Exogyra*, fragment of an upper valve of an undetermined species; *Pecten texanus* Roemer ?; *Turritella* sp.
75 to 85	*Ostrea* or *Gryphaea* sp.; *Requienia* sp.; *Nerinea* sp.
100 to 112	*Pecten?* sp., coarse ribbed form; *Nucula?* sp.; Wood?, imprint.
120 to 125	*Nodosaria* sp.; Corals, slender branching form; *Grammatodon?* sp.; *Leda* sp.; *Sphaera?* sp.; Solenid?, small slender shell with fine radial sculpture on posterior end; *Corbula* sp.; *Dentalium* sp.; *Turritella seriatum granulata* Roemer?; *Neriuea*, several sp.; *Fusus?* sp.
137	Foraminifera, number undetermined specimens probably mostly Miliolidae. *Pecten* sp.; large, coarse-ribbed.
153	Undetermined small pelecypods; *Nerinea* sp.
186 to 188	*Ostrea* or *Gryphaea* fragments; *Lima?* sp.; *Cyprimeria?* sp.; *Lunatia?* sp., small cast.
250 to 257	*Exogyra texana* Roemer; *Lima* sp.; *Protocardia?* sp.

The fossils from this drill core are all from depths between 40 and 257 feet and all belong to the fauna of the Comanche series. The lots from depths of 186–257 feet represent the fauna of the Comanche Peak and Walnut, and those from between 75 and 153 feet belong to the Edwards fauna. The lots from higher beds, 40–60 feet, probably also belong to the Edwards fauna, but in the absence of determinable diagnostic species there is a possibility that the basal part of the Washita group is represented in the well, though I do not consider this probable.

Dr. J. A. Udden and I collected fossils from near the top of a mesa 100 feet high which lies a short distance south of the railroad at the Santa Rita oil well, four miles east of the well from which the drill core was taken. The limestone capping of this mesa would ordinarily be called Edwards limestone, and the fossils also are such as have in the past been called Edwards types, but they belong to the faunal assemblage which near the mouth of the Pecos and on Devil's River is found in the upper 100 feet of Udden's Devil River limestone and above fossils that are characteristic of the Georgetown limestone. I am therefore classifying this rock as of Georgetown age.[1]

TRIASSIC

The Triassic deposits consist of dark red shales, gray and white sandy shale, calcareous cemented sandstones, and conglomerates.

[1] Personal communication to the bureau of economic geology, University of Texas.

Rather abundant mica is a characteristic of the gray sandstone as seen in drill cores, but in well samples this is seldom noticed because the loosely cemented sandstone is broken up by the drill and the mica is lost in the washing. It seems probable that some of the "lime" logged by drillers in this interval is calcareous sandstone or a conglomerate containing abundant pieces of limestone which is characteristic of parts of the Triassic.

So far as could be determined the thickness of the Triassic varies from 100 to 500 feet with an average thickness of about 300 feet. The great variation in the thickness of the Triassic appears to be due more to the unconformity at the top of the Permian than to the unconformity at the top of the Triassic. Thus the maximum thickness of the Triassic overlies the thinnest redbed Permian, and conversely a thin Triassic on the average overlies a thick Permian. These relations are shown graphically in Figure 4.

The drill core already referred to, taken by the Texon Oil and Land Company on Section 6, Block 2, about four miles west of the field, has been of material assistance in the study of the Triassic. Aside from this core relatively few samples were obtained from this series.

THE PERMIAN

The Permian in this field is not only of great thickness but presents a great variety of sediments. The uppermost Permian includes the redbed series consisting of clays, sands, salt, gypsum, and anhydrite. Underneath the redbeds is a great series of limestones, dolomites, and shales. The deepest well drilled in the field, approximating 6,000 feet, has not afforded evidence of having passed the base of the Permian.

THE PERMIAN REDBEDS

Within the redbeds as a rule three prominent salt series may be recognized, designated for convenience the first, second, and third salt beds. The several intervals above and below these salt beds into which this series may be divided are discussed in order. The Permian redbeds as a whole reach a thickness in this section approximating 2,500 feet.

Interval from the top of the Permian to the top of the first salt.— The exact contact of the Permian and Triassic is in most cases more

or less doubtful. The difficulty of determining this contact is increased owing to lack of adequate samples from this part of the section, it being difficult to convince operators and drillers that it is worth while to retain samples from these strata. However, an un-

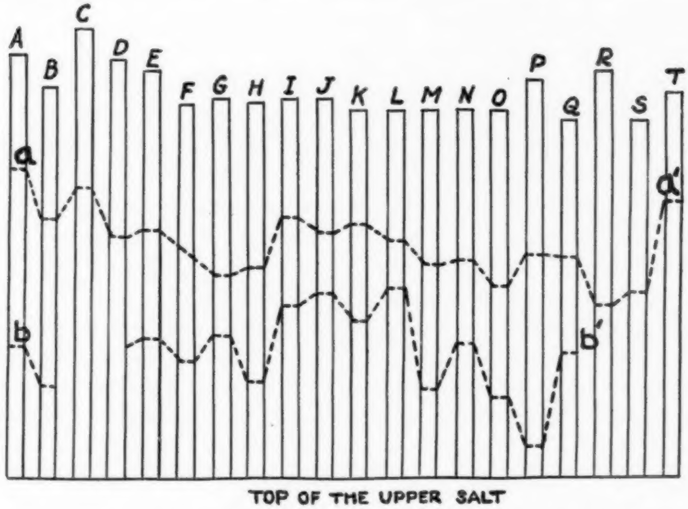


FIG. 4.—Well logs shown in outline to the top of the first salt. Scale: 1 inch = 500 feet. *aa'*, top of the Triassic; *bb'*, top of the Permian. The logs are placed with the first salt as a common level; the sketch thus indicates the varying thickness of the Permian above the first salt and the varying thickness of the Triassic. The irregular lines, *aa'* and *bb'*, indicate the Cretaceous-Triassic and the Triassic-Permian unconformities. The wells of this sketch are as follows: (*A*) Univ. 1, Associated Companies; (*B*) Univ. 1, Arkansas Fuel Oil Company; (*C*) Univ. 1, Transcontinental Oil Company; (*D*) Univ. 7; (*E*) Univ. 6; (*F*) Univ. 4; (*G*) Univ. 2; (*H*) Univ. 3; (*I*) Univ. 1; (*J*) Univ. 8; (*K*) Univ. 10; (*L*) Univ. 9; (*M*) Univ. 14; (*N*) Univ. 15; (*O*) Univ. 5; (*P*) Univ. 12; (*Q*) Univ. 11; (*R*) McIntosh 1, Mid-Kansas Oil and Gas Company; (*S*) Hughes 1, Mid-Kansas Oil and Gas Company; (*T*) Univ. 1, Hughes and Smith. Wells *D* to *Q* inclusive are owned by the Big Lake Oil Company.

conformity is indicated at the top of the Permian. The interval between the first salt beds and the Permian-Triassic contact varies from 100 to 575 feet with an average of about 350 feet. The strata in this interval consist of brick-red shales and fine-grained, brick-red, more or less shaly sandstones and some few beds of anhydrite.

The anhydrite, however, is much less abundant in this interval than below the first salt bed. In Figure 4 the well logs, shown in outline to the first salt, are arranged with the top of the upper salt as a common stratigraphic horizon. The Permian-Triassic and Triassic-Cretaceous contacts are indicated in the sketch.

The first salt beds.—Of the three salt beds, the first or uppermost is the thickest and most persistent. The average thickness of these beds approximates 500 feet, the minimum being about 270 feet and the maximum 630 feet. The samples obtained indicate that with the salt there is more or less anhydrite. This salt bed is also the most important potash-bearing zone in the field. Examinations made both by the university and by the United States Geological Survey indicate the presence of potash-bearing minerals in this zone; not as much, however, as is reported in many logs. A considerable portion of the salt at this horizon has a reddish tinge and there also occurs more or less reddish anhydrite. Some confusion has resulted from the fact that polyhalite usually has a reddish color and that it occurs in these beds. As a consequence drillers and others are apt to class as potash any distinctly red mineral in spite of the fact that polyhalite cannot be distinguished from anhydrite without the aid of chemical or mineralogical tests. The clear salt also in most cases yields tests for sylvite and it is possible that this mineral may be present in considerable quantities in some of the beds.

Interval between the first and second salt beds.—The interval between the first and second salt beds ranges in thickness from 300 to 800 feet. It contains thick beds of anhydrite alternating with red sandstone and red sandy shale. The anhydrite beds of this interval are from 200 to 250 feet thick.

The second salt beds.—The second or middle salt beds are rather poorly defined and not as conspicuous as either of the other two series of salt beds. In some cases the second salt beds consist of a single bed but more often of a number of beds separated by anhydrite, red sandstone, and shale; in some cases as many as five beds are present. The individual salt layers vary in thickness, the whole interval approximating 100 feet.

Interval between the second and third salt beds.—The interval between the second and third salt beds contains the principal an-

hydrite deposits of the section. There seem to be two rather well defined zones of anhydrite deposition although deposition of anhydrite is not confined to these zones and there are exceptions within them. Just below the second salt beds there are beds of anhydrite 150 or 200 feet in thickness. Again just above the third salt beds there is a rather persistent bed of anhydrite of about the same thickness. Between the two anhydrite beds are more or less conspicuous beds of red sandstone reaching a thickness of as much as 200 feet in some places, but in others being present only as thin strata alternating with the anhydrite and shale. Strata of sandy red shale and silty sandstone are of frequent occurrence but seem to follow no general arrangement. The thickness of this interval varies from 500 to 700 feet, the average being 550 feet.

The third salt beds.—The third or lowest salt beds occur at a level varying from 70 to 250 feet above the producing horizon. The salt strata vary in number from one to five, although frequently only one stratum is present. Where more than one bed occurs the strata are separated by anhydrite, sand, and shale varying from a few feet to 100 feet in thickness. In some cases there seems to be no sharp separation from the middle group of beds, thin salt beds alternating with other strata continuing through the entire interval.

PERMIAN LIMESTONES AND DOLOMITES

Below the third salt beds the sediments pass from sandstones, red clays, and anhydrite into calcareous sandstones, sandy dolomites, and pure dolomites. All gradations between the different materials may be seen. For instance, the filling or cementation of the sandstone is frequently seen to be of anhydrite; dolomite is found extensively intergrown with anhydrite; and the dolomite shows all variations from pure dolomite to calcareous sandstone. In this connection it should be noted that anhydrite is practically never correctly logged, as drillers almost invariably wrongly identify it as lime. For this reason subsurface contours drawn on the top of the lime, unless controlled by examinations of cuttings, are subject to a large possible error.

The producing horizon.—The sandy dolomite layers, underlying the third salt, have produced some oil. However, the principal pro-

ducing horizon in this field is oölitic dolomite varying in thickness from 10 to 60 feet, and averaging about 20 feet. From the third salt to this oölitic horizon is an interval varying in the wells from which samples have been obtained from 75 to 170 feet. As elsewhere stated, an unconformity probably occurs within this interval.

The oölites in this horizon are very numerous and in some cases make up nearly the entire rock. They vary in size from 0.2 mm. to

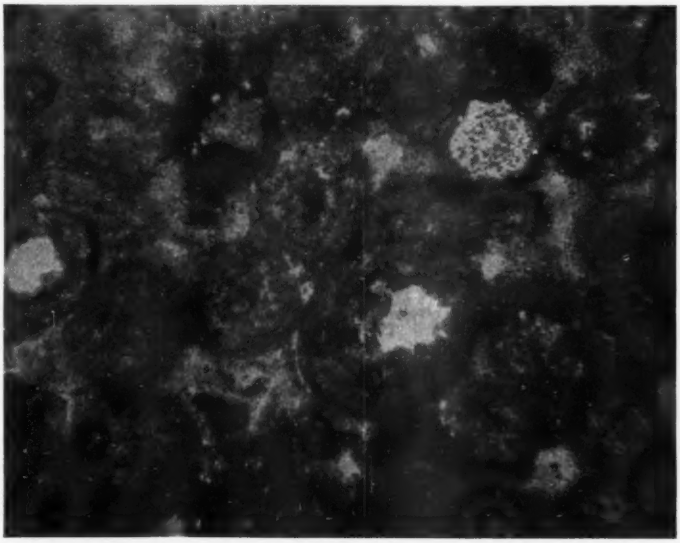


FIG. 5.—Photomicrograph of a thin section of oölitic dolomite, from Big Lake Oil Company well No. 12, depth 2,963–67. ×35.

0.5 mm., the greater number being near the latter size. They are concentric in structure and usually show a central body or nucleus, often consisting of a sand grain. Figure 5 shows a photomicrograph of a portion of a well sample indicating the proportion of oölites to other material. In many cases, the oölites break out from the matrix when the rock is broken up by the drill and are found in the samples as separate particles (Fig. 6). On the other hand the oölites are in some cases firmly imbedded in the matrix, but the rock is nevertheless quite porous. In cases where oölites break out easily from the

matrix they might be mistaken for coarse sand by a casual observer, and in one case at least they were so recorded by the driller. This may partly account for the persistence with which the drillers insist that the production comes from a sand. Microchemical tests show that, aside from the occasional sand grain nucleus in the oölites, the rocks vary from relatively pure limestone to pure dolomite. This oölitic zone is not only a distinctive but a very constant zone and there is practically no instance of a well within the field, of which a complete and carefully kept set of samples is available, in which this zone is not easily and definitely identified.

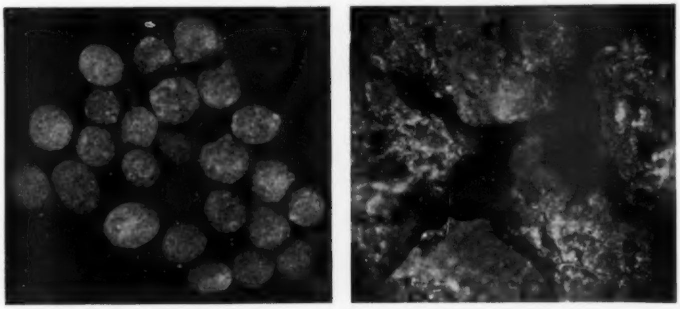


FIG. 6.—Individual oölites picked from well samples, and porous dolomite from the producing horizon. ×11. The oölites are from Hughes and Smith well, Sec. 5, depth 3,375 feet; the dolomite is from the Big Lake Oil Company No. 12, depth 3,040 feet.

Sediments below the producing horizon.—Samples obtained from wells near the field indicate that the sediments for as much as 300 feet below the oölitic zone of the main producing horizon consists of dolomite, sandy dolomite, and sandstone. In the Hughes well of the Mid-Kansas Oil Company (Sec. 25, E. G. & R. RR. Surv.) at 280 feet below the producing horizon is a second oölitic dolomite. The deepest well drilled in this field approximated 6,000 feet. From this well (Univ. 1, Group 2, Texon Oil and Land Co., SW. ¼ Sec. 22, Blk. 9), samples were obtained from 4,855 to 5,710 feet. Of this interval, the first 100 feet consist of sandy shale, some of which is dark in color, in which, particularly in the dark strata, radiolaria are found in some abundance. Next below this shale is found 80 feet of

calcareous sandstone with a little dolomite. The next lower 600 feet in the well consist almost entirely of dark, almost black, carbonaceous shale, with occasional strata of gray shale and a little sandy shale, grading upward into a lighter, more sandy shale. Chloroform extraction tests show traces of oil in many of the samples. The only fossils found in this interval were radiolaria, which occur at various levels throughout the interval. Dr. J. A. Udden[1] has suggested that the abundance of radiolaria may indicate the Word formation of the Permian, similar occurrence of radiolaria having been observed by him in this formation. On such evidence as is available these sediments are tentatively referred to the Permian. From the lower 290 feet in the well, 5,710–6,000, no samples were obtained.

The section in this field to a depth of 5,700 feet thus includes Comanchean, 500 feet; Triassic, 300 feet; Permian, 4,900 feet. Since unconformities are present, these thicknesses, although representing averages, will be found to vary in individual wells.

SOURCE OF OIL

The source of the oil is undetermined. It may originate in the strata in which it is found or may be derived from the great body of bituminous shales which, as indicated in the generalized section, underlies this field. Aside from the main producing horizon in the oölitic dolomite, considerable gas and some oil is obtained from sands within the redbeds at a depth from the surface of about 2,400 feet.

STRUCTURE

A structure map made on the water sands near the base of the Comanchean indicates that the Comanchean sediments reflect little if any of the structural features of the producing horizon. The dip appears from data on the water sand to be above normal at the west edge of the field and possibly below normal over the remainder of the field. If, therefore, the Comanchean is affected at all by the structural conditions in the field, the change from normal dip amounts to nothing more than terracing. Aside from the Comanchean the first horizon recognized throughout the field is the large salt bed.

For structural mapping, an oölitic horizon lying within the pro-

[1] Personal communication.

ducing zone has been found the most readily recognized. The nature of the strata immediately overlying and underlying this horizon together with its own distinctive characteristics makes its recognition possible in dry as well as in producing wells. For this reason this horizon has been selected as the key horizon in mapping the struc-

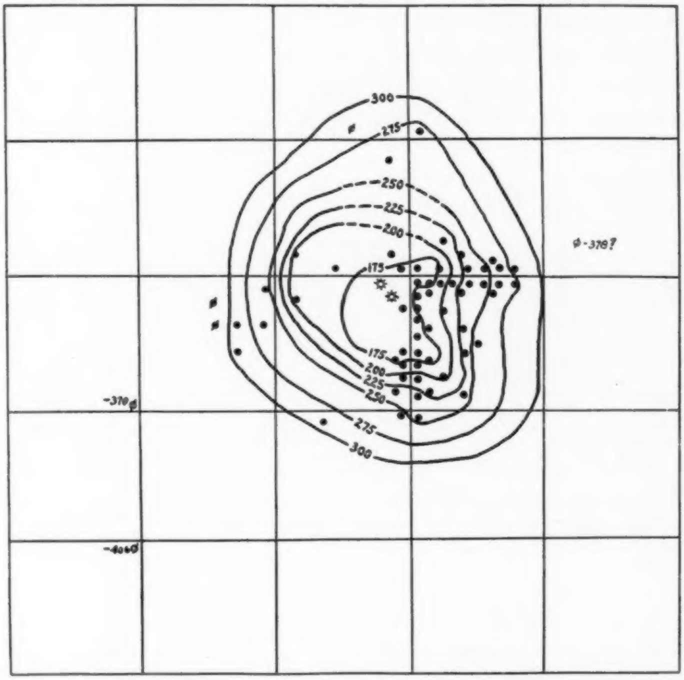


FIG. 7.—Structure map of the Big Lake oil field. Contours on the oölitic zone of the producing horizon.

ture. It has already been shown, however, that the presence of a few oölites within the rock does not establish this horizon. Oölites are found both in the sandy dolomite above and in the dolomite below this horizon, and as stated above there is another zone of oölitic dolomite 250 or 300 feet below the main zone.

A structure map on this horizon shows pronounced doming in the

Permian below the redbeds, the closure on the dome being not less than 125 feet and probably considerably more. At the high point on

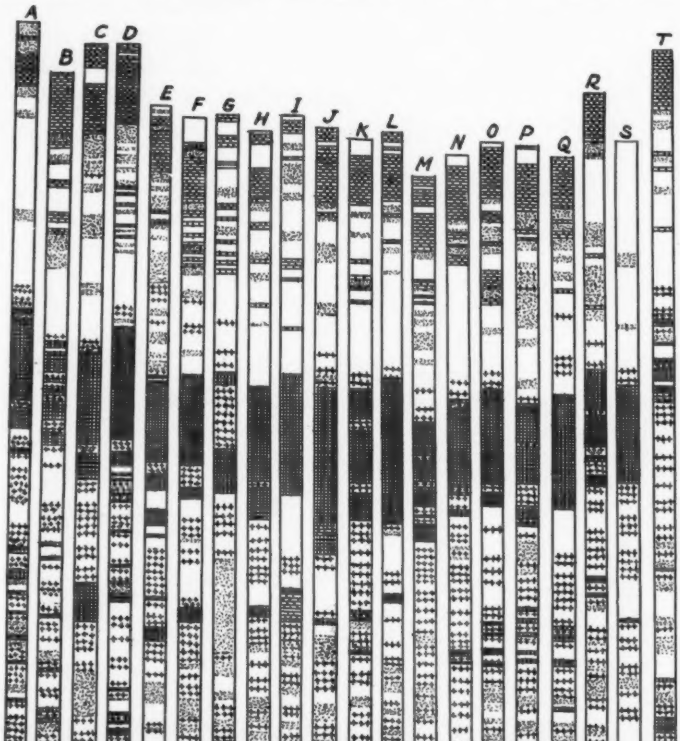


FIG. 8.—Well logs placed with the oölitic dolomite of the producing horizon as a common level. Wells *A* to *C* are south of the field, while wells *Q* to *T* are north and northeast. The other wells are in or near the field. *aa'* is the oölitic dolomite of the producing horizon. The interval from the first salt to the producing horizon is variable, being in general less within the field than elsewhere. The wells are the same as those of Figure 4. Scale: 1 inch = 800 feet.

the dome the producing horizon is found at about 160 feet, while down the sides of the dome production extends to about 350 feet, sea-level datum. Contours on the oölitic dolomite, which is the principal producing horizon, are shown on the structure map (Fig. 7). A structure map contoured on the first salt shows less intensive folding, although the closure on the salt within the producing area is at least 75 feet.

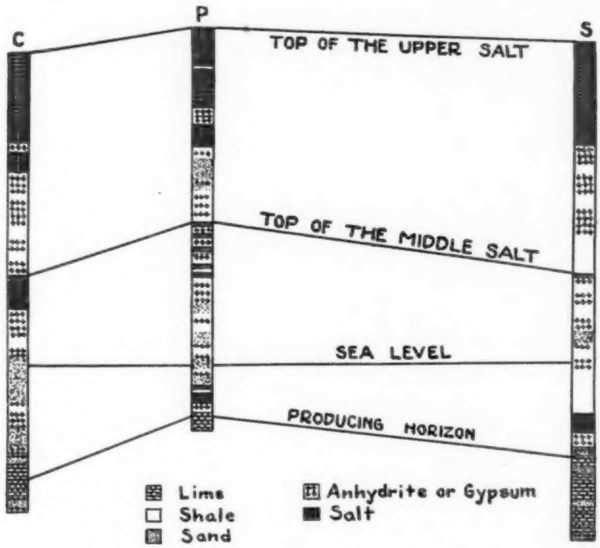


FIG. 9.—Wells *C*, *P*, and *S*, of Figure 8, placed according to sea-level elevations, but with that part of the log above the first salt omitted. Scale: 1 inch = 800 feet.

UNCONFORMITIES

As indicated in the generalized section (Fig. 3), unconformities are found in this section at the base of the Cretaceous and at the base of the Triassic. That there are also unconformities in the Permian seems highly probable. The interval from the first salt beds to the oölitic dolomite in the main producing horizon varies in thickness as much as 420 feet. The variation is least where the salt beds lie directly above the high points of the subsurface structure and greatest where the salt beds lie above the low points on this struc-

ture. The large variation in this interval suggests the probability of an unconformity at some place between the oölitic dolomite and the upper salt beds.

The relation of the upper salt to the producing horizon is indicated in the series of logs shown in Figure 8. This difference in the interval is further illustrated in Figure 9 in which wells *C*, *P*, and *S* of the previous illustrations are placed according to sea-level elevations.

If such an erosion interval between the first salt and the producing horizon exists, it is desirable to ascertain where it is in the section. The evidence in this regard is not at all conclusive on account of the lack of identifiable key horizons within the redbeds, the salt beds being about the only ones which can be so used. Because of the rather poorly defined character of the middle salt beds they make a very unsatisfactory key horizon. However, these beds seem to occupy a stratigraphic horizon roughly parallel to that of the upper salt beds. The lower salt beds are even less well defined, but seem also to be roughly parallel to the upper salt beds. It is therefore probable that there is an unconformity in the section at the base of the redbeds.

ORIGINAL SOURCE OF OIL IN COLOMBIA

F. M. ANDERSON
Berkeley, California

ABSTRACT

The Cretaceous rocks of Colombia, including the Jiron, Villeta, and Guadalupe groups, have been laid down upon an ancient floor of metamorphic and crystalline rocks. The lower and upper groups of the Cretaceous are very largely detrital in origin, while the middle group is partly detrital and partly of organically derived limestones and marls. Dr. Otto Stutzer has claimed that "All of the oil in Colombia probably emanated from the Villeta group, that is, the Lower Cretaceous." There are no wells yet drilled in Colombia that derive a production from Cretaceous beds, nor is any part of the Cretaceous more than sparingly bituminous, although suitable structures are abundant.

On the other hand, all of the producing wells in Colombia are in Tertiary formations and are drilled in situations such that it appears highly improbable that the oil could have emanated from Cretaceous strata, especially from the Villeta group. Moreover, the older Tertiary (Eocene and possibly Oligocene) strata are in many places richly organic and more highly bituminous than the Cretaceous and the producing wells have been drilled into them, and the presumption is strong that they have been the primary source of the oil that is being produced.

In parts of Colombia where the older Tertiary beds are purely marine, foraminiferal remains are abundant and could constitute the source material of the oil. In other parts of the country where the older Tertiary beds are non-marine they include lignitic and carbonaceous strata, such as might have contained the source material of the oil, as is the case in Trinidad and, perhaps, also in some of the oil fields of the Maracaibo basin in Venezuela.

In a brief paper no complete account can be given of the various groups of strata with which oil or its evidences are associated in Colombia, since they have been found in all of the major series and have been reported associated even with crystalline rocks in certain districts. It may be stated at the outset, however, that no commercial production of oil has yet been obtained from any strata older than the Tertiary.

BASEMENT ROCKS

The geologic column of Colombia includes among its oldest rocks certain pre-Cretaceous quartzites, limestones, and crystalline schists which crop out only in relatively small areas and which are much involved with granites, diorites, and other irruptive types, but they have little interest for the oil man. Some of the older sediments probably represent Paleozoic periods, perhaps not now capable of identification. The largest area of these basement rocks is that of

the central cordillera, which occupies almost the entire region between Cauca and Magdalena rivers, the axis of which, when followed northward gradually, descends until, in the vicinity of El Banco, it passes beneath the valley and is crossed by Magdalena River. Farther north rocks of the same types appear, serving to connect the central cordillera with the Sierra de Santa Marta. Basement rocks occur also west of the Cauca Valley, where they are said to include various types of porphyries, porphyrites, and ancient volcanic types, along with basic plutonic rocks with which platinum metals are associated. In the central cordillera there are many metaliferous veins, and some mines of considerable renown.

In the eastern cordillera the basement rocks appear only in small scattered areas about the higher ranges. They doubtless represent the northern extension of the Brazilian complex described by Branner,[1] and as such form a part of the ancient framework of the continent. From it was primarily derived all of the later sediments.

CRETACEOUS SERIES

The Cretaceous period was one of prolonged subsidence in this part of South America. Upon the basement complex was laid down an enormous series of Cretaceous strata, the total thickness of which approaches 20,000 feet. This aggregate is composed of diverse groups and members, differing in origin and lithology, and for which a completely conformable sequence has not yet been established.

No other sedimentary series has so large an exposure in Colombia as the Cretaceous, for it composes almost the whole of the eastern cordillera, nearly 800 miles long and 40 to 80 miles wide. There is a large Cretaceous area along the south border of the Sierra de Santa Marta, another along the Cauca Valley, and Cretaceous beds crop out in some of the smaller ranges of northern Colombia.

Beds more or less organic in character are found in all parts of the series except the Jiron group, which makes up the lower one-half of the series. Marls and limestones, which are probably largely of organic origin, follow immediately upon the Jiron group, as may be seen near Zapatoca, but they contain scant evidences of petroleum. In a large part of the eastern cordillera limestones predominate in

[1] *Bulletin of the Geological Society of America*, Vol. 30, pp. 189–338.

the groups following the Jiron, but while in some districts they are more or less bituminous, they are generally without seepages of oil or even asphaltic residues. The Guadalupe group, forming the top of the Cretaceous section, contains organic strata, but for the most part it is detrital in origin. Below (Table I) is shown a tabular outline of the Cretaceous groups, which, with the exception of the second, have been usually recognized by earlier writers, most of whom were Germans.

CRETACEOUS STRATA IN COLOMBIA

Epochs	Groups	Characteristics
Upper Cretaceous	Guadalupe	Sandstone and sandy shales; dark clay shales, usually hard; siliceous shales, or cherts, with foraminifera, but with few fossil mollusks; contains locally lignitic or carbonaceous beds; 4,000 feet
Middle Cretaceous (Aptian and Albian)	Villeta	Gray or dark clay shales and sandstones; thin-bedded limestones, more or less bituminous; marls sometimes sandy, with echinoids, *Asterias*, and near-shore mollusks; locally richly fossiliferous shales and limestones; 1,500 to 2,000 feet
Barremien and Hauterivien	Suarez	Red sandstone, locally very thick; thin-bedded limestones and marls, with *Crioceras*, *Hoplites*, *Puzosia*, etc., 1,500 to 2,000 feet
Lower Cretaceous	Jiron	Red sandstones and variegated sandy shales without fossils; white sandstones, often in thin beds; local conglomerates; 10,000 to 12,000 feet

No petroleum has been reported in the two lower groups of the Cretaceous and none seems likely to be found, at least in the lowermost.

The Villeta group, lying well above the middle of the Cretaceous section, contains the earliest evidences of petroleum known in Colombia, but they are not impressive. Where the group occurs along Suarez River, as at Velez, it contains "bituminous limestones," with thin beds of shale and sandstone in its upper part. In the region of Villeta and on the border of the plateau near by, clay shales predominate, with subordinate limestones. Thin-bedded sandy shales with concretionary layers are found, in which fossils are locally abundant, but thick aggregates of limestone are not found. Along

the west foot of the eastern cordillera, farther north, concretionary shale, and occasionally fossiliferous limestone occur, belonging to the upper part of the Villeta group. Seeps of asphaltic oil are reported from these beds in some places, but none of these were seen by the author. On the basis of such occurrences it has been claimed that "probably all the oil in Colombia has emanated from the Villeta group,"[1] which statement must of course include the oil districts along the foothills north and south of the lower Sogamoso, proved and prospective. As in this zone no commercial production of oil has been obtained from Cretaceous rocks it would appear that this view has at best only a speculative basis, not supported by actual production of oil, and, with some few exceptions, this seems to be the case with the districts about the Maracaibo basin in Venezuela.

Above the Villeta strata is the Guadalupe, consisting largely of sandstone, sandy shale, and an important member of peculiar lithology consisting of white siliceous shale or chert, which apparently is of organic origin, but in which, for the most part, only foraminiferal remains can be recognized. It has been compared to the "Planter beds" of Western Europe, especially by the German geologists. It appears to occupy the lower part of the Guadalupe group, as in the near vicinity of Bogotá. Coal beds have been reported[2] in this group, especially near the top. Seeps of asphaltic oil have been found issuing from the lower member of the group, but whether it originates in this or in the underlying group, has not been determined. In some localities the cherty beds of the lower member are bituminous, even where no oil seeps are found.

No oil in commercial quantities has yet been found in close association with either the Villeta or Guadalupe groups, though doubtless one or the other underlies all the territory actually yielding oil, or that seems likely to yield commercial production. This fact forms theoretical basis for the surmise that the oil of Colombia originates in the Cretaceous, though not necessarily in the Villeta group. It does not prove that it originates in either, or in both, or

[1] O. Stutzer, "Erdol-und Asphaltaustritte in Eruptivgesteinen und Kristallinen Schiefern des Mittleren Magdalenantals (Kolumbien)," *Zeit. d. Deutsch. Geol. Gesells.* (1923), Bd. 75, p. 187.

[2] A. Hettner, *Die Kordillere von Bogotá* (1892).

that commercial production will ever be obtained from them, though stratigraphically and structurally both are well constituted for such production.

Structure of the Cretaceous.—In the Cretaceous strata of the eastern cordillera there are many folds, ideally fitted to serve as reservoirs for oil and gas if either existed in these rocks in quantity. Extensive anticlines are known in each of the Cretaceous groups, where important accumulations should be found if any existed. Some of the largest folds involve the strata of the lower groups, from which the upper groups have been removed by erosion. In other cases the Villeta or Guadalupe beds form the surface and cover the lower groups.

An anticline passing near the village of Villeta has a longitudinal extent of about 100 miles, and along Suarez River, farther north, the folding is continued in a parallel line for another 100 miles. Between these two folds other anticlines are developed in an *échelon* fashion. Another anticline of considerable extent lies near the village of Villa Pinzon, and others are described by Hettner and by other geologists.

No direct evidences of important deposits of petroleum have been noted along any of these folds in the Cretaceous strata, as far as known, though bituminous limestones and small oil seeps, or asphaltic residues, have been seen. Most of the seeps are found in the Guadalupe beds, while bituminous limestones are reported in the Villeta group.

TERTIARY SERIES

Tertiary rocks cover a large part of northern and western Colombia, almost to the exclusion of all older formations. They form a considerable zone along the west coast, occurring at intervals southward from the Isthmus of Panama. They cover the entire northern coast line from the Gulf of Urabá east to Santa Marta, at the foot of the high Sierra of this name, and eastward from this range. They extend inland along all of the larger valleys, making up a large part of the low country about the Magdalena, Rio Cesar, Lower Cauca, San Jorge, and Sinu rivers. Beds of Tertiary age are found also in the upper valleys of Magdalena and Cauca rivers, and in the larger valleys of the plateau, or eastern cordillera, even at elevations of 8,000

to 9,000 feet. Tertiary rocks are said to occur also high on the broad eastern slopes of the eastern cordillera, on the headwaters of Orinoco River.

All the Tertiary periods from Eocene to Pliocene are possibly represented in Colombia, though in very unequal areas. Detailed mapping has been done by some of the oil companies, but only within small districts, and data from this source are not now available. Both marine and non-marine Tertiary deposits abound in Colombia, and in certain districts there are estuarine deposits. In the low country, as along the north coast and along the larger river valleys,

TABLE II

CLASSIFICATION OF COLOMBIAN TERTIARY

Periods	Magdalena Valley	Cartagena District	Sinú River Region	Lower Sogamoso	Upper Magdalena	Plateau Region
Pliocene..........	Galapa group	La Popa group	Escondido group	Honda beds	Honda beds	?
Miocene..........	Tuberá group	Turbaco group	San Antonio group (Beck)	Oponcito group	Barzalosa beds	Miocene group (Berry)
Oligocene........	San Juan group	?	Bombo shales (Beck)	?	?	?
Eocene...........	Carmen group	Arjona group	Tofeme-Coloso group	La Paz series	Guaduas beds	Guaduas beds
Cretaceous.......	Upper Cretaceous	?	?	Guadalupe group	Guadalupe group	Guadalupe group

marine Tertiary beds occur more commonly, whereas on the plateau they are non-marine, and in some intermediate stations they are estuarine. Few fossils have been found in the Tertiary of the plateau except plant remains.

The most characteristic and complete section of the Tertiary beds is found in the marine province, but it is not yet possible to give an adequate description of them. A tabulated summary statement of the beds found in some of the more representative districts of Colombia is given in Table II.

The distribution of the Tertiary is, for the most part, correctly shown on the geologic sketch map of Colombia, published by Huntley and Mason, in 1923,[1] though no attempt was made to differentiate the several Tertiary series. On account of structural complica-

[1] Huntley and Mason, *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 68 (1923), p. 1015.

tions they can never be correctly mapped in detail in many parts of the country. In the coastal region of Colombia the Tertiary strata not only stand at high angles, but in many districts the dense jungle so impedes geologic work that mapping is impossible.

Organic strata and bituminous beds especially characterize the Lower Tertiary, while oil seeps, asphaltic residues, mud volcanoes (Figs. 1 and 2), and other types of gas vents abound in all parts of

FIG. 1.—Part of a group of mud volcanoes near Aguila, west of Monteria, Colombia.

the Tertiary. Many of these evidences occur far from any outcrop of Cretaceous strata, and therefore are presumably independent of any older rocks which could act as a possible source for petroleum.

EOCENE SERIES

Marine Eocene.—The first published mention of Eocene rocks in Colombia was based upon the recognition of Upper Eocene foraminifera by Dr. J. A. Cushman[1] in a collection from Arroyo Hondo in 1919. Since then numerous collections of Eocene molluscas and foraminifers have been made by oil geologists, though no published accounts of them have appeared to date. Eocene rocks are widely dis-

[1] T. W. Vaughan, *U.S. National Museum Bulletin 103* (1919), p. 197.

tributed over the low country of Colombia, particularly in the southern part of Bolívar. They cover a large region west of the Magdalena, extending in a wide zone from Arroyo Hondo southwest to Cienega de Oro, and thence along the west flank of the San Jeronimo Range to the headwaters of Sinú River. West of the Sinú they make up a considerable part of the ranges along the coast, the highest of which is known as the Cerros de Las Palomas.

FIG. 2.—A mud volcano near Turbaco, 12 miles from Cartagena, Colombia

Eocene strata include the main coal-bearing formation of Colombia, as they do also in Venezuela, and occupy the basin of San Jorge River, and perhaps the east flank of the San Jeronimo Range. A single specimen of *Venericardia* and accounts of coal near Rio Hacha are taken as evidence of the existence of Eocene there. The same rocks extend south from this point into the valley of the Rio Cesar, as we interpret the section drawn for this region by Washburn and White.[1] Judging from lithology, Eocene rocks occur also about the Gulf of Morrosquillo and Cispata Bay, bordering the Carmen–San Andres zone, where they have been definitely proved by marine molluscs.

Most of the Eocene west of Magdalena River, except the coal-

[1] Washburn and White, *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 68 (1923), p. 1026.

bearing group, is of marine origin, and the coal-bearing beds are intercalated between marine strata. These beds lie somewhat below the middle of the proved Eocene series, at least in its marine province. The marine facies of the Eocene is perhaps well represented by the section found near El Carmen, where a great thickness of Eocene strata has been proved.

From the western border of this series, near Cansona, a rough profile was made across the strike toward Zambrano, on Magdalena River, in which Lower Tertiary beds attain a total thickness of more than 6,000 feet. Of this the proved Eocene constitutes at least 4,500 feet, which may be divided into the following groups:

	Thickness (Feet)
G. Clay shale, sandy clay shale, white siliceous shale, probably organic (not known to be the top)	1,000
F. Concretionary sandy shale, sandstone, etc., with molluscan fossils, foraminifera, petrified wood, etc.	600
E. Yellow, thin bedded sandstone, weathering red	400
D. Whitish shale, with lenses and thin beds of limestone, sandstone, etc. (Tofeme group, with thin beds of lignite and carbonaceous matter near bottom)	800
C. Earthy or hard, thin-bedded, siliceous shale, marly shale with lime stone, containing molluscan fossils	800
B. Yellow concretionary sandstone	500
A. Heavy beds of sandy conglomerate (near Cansona)	400
Total	4,500

The thick body of shale above the basal members, over 1,600 feet in thickness, appears to be largely organic, though the nature of the organisms is not known, except for the small molluscan fauna and the great abundance of foraminifera found in some places and the lignitic and carbonaceous beds noted near the middle of the shale.

The siliceous character of the shale, in part, recalls the siliceous shale in the Tertiary of California, whose origin may indeed be similar. Other parts of this shale are decidedly calcareous, suggesting foraminiferal origin. The shale constitutes more than one-third of the proved Eocene series, largely organic though not conspicuously bituminous, while other parts of the series are also organic.

It thus appears that marine Eocene rocks cover a large part of

the surface of southern Bolívar, and extend thence into the departments of Atlantico, Magdalena, and, probably, Santander. It would be interesting to note in detail all of the manifestations of petroleum associated with these rocks throughout the low country, but only summary statements can be made here. Oil springs, asphaltic residues, gas springs, mud volcanoes, and other evidences of oil follow the Eocene throughout, appearing at places where structural conditions permit within the Eocene strata, and at other places in strata

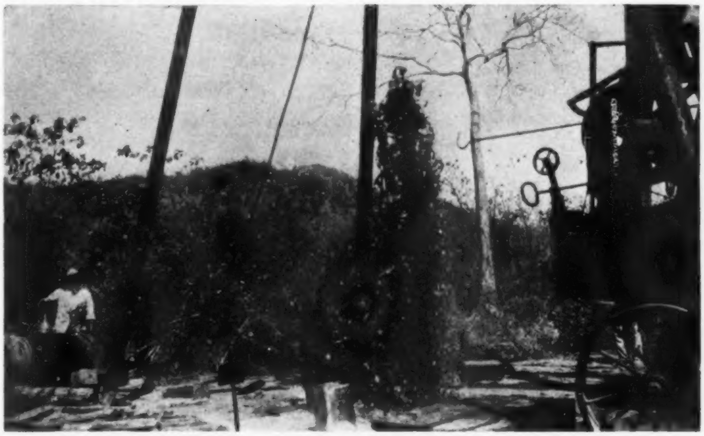


FIG. 3.—Flowing oil well near Puerto Colombia, May, 1922

immediately above them (Fig. 3). Many such occurrences are found at places far removed from any outcrop of Cretaceous rocks, as along the north coast west of the Sinú Valley (Fig. 4). In fact, in the low country, wherever oil or gas springs are found, Eocene rocks are either exposed at the surface or are hidden not far beneath, whereas Cretaceous rocks are rarely present at all. Furthermore, the Eocene series is more characterized by the presence of organic materials than any other that could possibly be concerned with the occurrence or origin of oil in most of the low country of Colombia.

Non-marine Eocene.—Where delta-like or shallow lacustrine conditions have existed during Eocene times, corresponding deposits have been formed, and accordingly estuarine deposits containing

faunas that are only in part marine, and other deposits that are without any marine aspect, have now come to be recognized in different parts of the country. Along the west foot of the eastern cordillera, as at the *débouchure* of the Magdalena and its larger tributaries, the Rio Carare, Rio Sogamoso, Rio Lebrija, and perhaps in the valley of the Rio Cesar, if not also in the basin of the San Jorge, estuarine conditions, or at least conditions not altogether marine, have been abundantly developed. Brackish-water faunas

Fig. 4.—Flowing oil well near San Sebastian, Sinu Valley, March, 1915

have been found on the Rio Sogamoso, Rio Colorado, Rio Magdalena, and at other such places, showing estuarine conditions here during Eocene time. In the upper valley of the Magdalena strata of such character have been embraced under the name of Guaduas beds, and were formerly thought to form a part of the Cretaceous series. More recently they have been regarded as Eocene, and are believed to correspond in age to the marine Eocene of the coastal region and the low country of Colombia. A brackish-water fauna has recently been found within the area of the type locality of the Guadas series, such as should characterize estuarine deposits of the Eocene. It includes *Ampulina*, *Cyrena*, *Corbula*, *Spherium*, and *Goniobasis*, along with indistinct plant remains. Similar fossils have

also been found near Tocaima. While the Eocene age of the series has been determined upon other grounds, its stratigraphic relations to the Cretaceous below, and to the Miocene above, indicate that it is at least Lower Tertiary in age.

The Guaduas series has been followed or identified not only on the border of the plateau, as at Guaduas, Tocaima, and Cipacon, but it has also been found upon the plateau itself, and far in its intermontane valleys. It occurs at Bogotá, Nemocon, Tunja, Santa Rosa, and near Bucaramanga. It has also been found at Pamplona and the headwaters of Zulia River. It is believed to extend along the eastern foot of the eastern cordillera and to pass thence into the drainage of the Catatumbo and the basin of Lake Maracaibo, where similar deposits are well known, though not definitely identified with the Guaduas.

Although no molluscan fossils have hitherto been reported from the Guaduas series in the intermontane valleys of the plateau, they nevertheless have been found, and it cannot be said that they are marine. In fact, the Guaduas series of the plateau has been generally believed to be entirely non-marine, and of fresh-water origin.

On the plateau the Guaduas series includes nearly all of the coal beds known at the present time, according to Dr. Robert Scheibe, who for some years represented the Comisión Cientifica Nacional at Bogotá. Coal also characterizes the Guaduas series in the upper valley of the Magdalena, but it is found also farther north in beds that should be correlated with the Guaduas, in the estuarine areas of the Eocene. At Cipacon, Tequendama, and Guasca, an Upper Eocene flora has been found,[1] and these localities are almost continuous with many others mentioned above including the type locality of the Guaduas, containing a brackish-water fauna. The coal beds found in all of these localities serve also to confirm the proper correlation of their strata with the beds in which coal occurs at Morenga, Las Doradas, San Vicente, Rio Carare, Rio Sogamoso, and at other points along the west foot of the eastern cordillera.

The maximum thickness of the Guaduas series on the plateau is estimated at 6,500 feet, a figure quite comparable with that of the marine Lower Tertiary series in the Carmen-Zambrano section, and

[1] E. W. Berry, *Bulletin of the Geologic Society of America*, Vol. 35 (1924), p. 782.

greater than that assigned to the Eocene itself. In the Guaduas of the plateau, the coal veins, unlike those of the lower country, occur at the bottom of the series, in a vertical range of 700 to 800 feet, and, with reference to the whole series, somewhat lower than the similar beds in the marine series.

There are many places along the west foot of the cordillera where springs of asphaltic oil issue from Guaduas strata, and many others where beds of bituminous sands are found. Such occurrences are well known south of Sogamoso River, in the upper valley of the Magdalena, and along the Rio Negro, Rio Seco, and at other points farther south. They are found also in later beds.

While it has not been definitely proved that the oil production of the Sogamoso district is derived originally from Guaduas strata or from their equivalents of the La Paz, this should be surmised from a general study of the strata associated with the oil deposits; if it be determined that this oil comes directly from strata later than the Guaduas, it may still be believed that it originated in this group. In this district the Guaduas (LaPaz) series is said to aggregate a thickness of 10,000 feet or more, beneath which should normally lie the strata of the Guadalupe (Cretaceous). Under such conditions only theoretical assumption can support the view that this oil originated in the Cretaceous beds, but such an assumption would be far-stretched to apply it to the Villeta group of the Cretaceous.

It is held by some geologists that estuarine, or delta, conditions are favorable or even necessary for large accumulations of petroleum, and that petroleum is formed by the alteration of land-derived materials that find lodgment chiefly under delta conditions. Vegetable matter in the form of humus, plant débris, or even wood brought down by rivers, especially in tropical countries, has been suggested as the material from which oil is derived under the chemical processes of nature. It may be pointed out that the chief essentials required by this view are undoubtedly present here, just as they are in the basin of Maracaibo, which has been mentioned by Cunningham Craig as an example supporting the hypothesis. Magdalena River, the Carare, Opon, Colorado, Sogamoso, and Lebrija rivers, all enter the delta area which embraces the only oil district of commercial

value yet proved in Colombia. These delta conditions existed also during the Eocene (Guaduas) time, and the lignitic and carbonaceous beds within the delta area bear witness to the accumulation of vegetable matter and, incidentally, of all the various products of plant decomposition, partial, special, or other, in all stages of the process. The area should, therefore, supply data comparable to any other to support, or illustrate, the soundness of this conception.

But on the other hand, may there not be other sources, or other forms of organic matter, not necessarily within the delta, to be considered as the possible origin of the petroleum of this district? The delta area is not entirely free from marine conditions, as may be seen from the character of the molluscan fauna found even in the mountains of the upper valley of the Magdalena. The inflow of the tides may possibly have brought marine organisms within its area and impounded them there in great numbers. But in the purely marine areas of the Eocene, organic matter abounds in the form of many types of foraminifera, if not of other organisms, animal or plant. In any case, estuarine and marine conditions, organisms, and deposits should mingle at the extremities of the delta. As must result under such conditions of deposition, the lateral migration of petroleum in all its forms could take place, and the trend of migration would naturally be toward the delta head, where more porous strata and otherwise suitable conditions are developed for its permanent lodgment.

How far the lateral migration of oil may be carried in the process of its accumulation, during the course of several million years, is not known, but if lateral migration is effective at all, the time since the period of deposition has been ample to carry its operations up the delta channels to its head, however slowly it may have proceeded.

Whichever view may be accepted as to the primary source of the oil, marine or non-marine, there is an abundance of either, or both, in the Eocene beds to supply all that can reasonably be demanded by theorists. Furthermore, it is in accord with sound logic to assume that petroleum deposits originate within the formations in which they are found, unless there is convincing evidence to the contrary. In this case no such evidences are known, at least not such as would

lead us to infer that all the oil in Colombia had "probably emanated from the Villeta group, that is, the Lower Cretaceous."

Structure of the Eocene.—In the low country of Colombia the Eocene strata are much folded, and in many places faulted, as are also all the strata overlying them. An anticlinal fold extends for a distance of about 100 miles in a southwesterly course from near Calamar, on the Magdalena, to San Juan, El Carmen, Sincelejo, and San Andres. In the region of the Coloso Range the Bolívar fault

FIG. 5.—Border of pool at summit of "mud volcano" mound covering nearly 40 acres, near Bay of Arboletes, Colombia.

traverses the west foot of this range, extending from here south toward Montería, and north toward San Cayetano. Other folds and faults also traverse the Eocene of this region.

Along the coast west of the Sinú Valley the folds of the Tertiary are high, including those of the Eocene, and are much broken by faulting. Where faults occur there are often found oil seeps and asphaltic residues, though not often large. Oil seeps are found locally along the folds, though more frequently there are gas springs, mud volcanoes, etc., some of which are of large proportions. Near Arboletes Bay a mud mound, 75 to 80 feet high and covering nearly 40 acres of land, rises on the axis of a fold. Upon the same fold, farther north, are found other gas-springs and seepages of oil (Fig. 5). Another cluster of mud volcanoes near Aguila, west of Montería

(Fig. 6), covers about the same area, and rests upon the axis of a fold in Lower Tertiary strata.

In the district of the lower Sogamoso the Tertiary strata are much folded and faulted. A number of somewhat parallel folds traverse this district in a general northeast-southwest direction, their extent and character being not yet fully known. The Infantas anticline is a sharp, and in part overturned, fold, involving the entire

FIG. 6.—Cluster of "mud volcano" vents and mud flow from their joint action, near Aguila, west of Monteria.

Tertiary series, along which there are large asphaltic deposits. Other folds farther east are said to show even greater outpourings of asphalt.

On the eastern border of the district, at the first ascent of the cordillera, faulting of the Tertiary beds has exposed its lowest members, showing some of the coal beds occurring near the base of the La Paz (Guaduas) series. As no evidences of oil were observed here, and as the shale, as far as exposed, seems barren, it is inferred that the oil horizon of the district is in the upper part of the series. The folding of the Tertiary beds here involves the Oponcito group as well as the La Paz, though the absence of any organic strata, or of any beds in it that might be the primary source of petroleum, seems conspicuous.

OLIGOCENE SERIES

Little can be said at present concerning the existence of Oligocene rocks in Colombia. In view of their occurrence and importance in neighboring regions, such as Jamaica and Panama, they should be expected here. They appear in the basin of Maracaibo, where, according to Arnold, they may be the source of some of the oil of that region.[1]

In the Carmen-Zambrano section, between the proved Eocene strata and the base of the Miocene, there are over 1,800 feet of clay and sandy shale that may wholly, or in part, belong to the Oligocene, though it may also be Eocene. In the section of the Tertiary drawn by Beck,[2] representing the conditions near San Andres, there are strata between the Eocene Tofeme group and the known Miocene which are partly embraced in a group which he calls "Bombo shale." This group, the thickness of which he places at 500 feet, should perhaps be attached to a portion of a group following which he calls "Huertas series." Together they may represent the Oligocene. According to a verbal statement of an American geologist, samples of foraminifera taken from the Bombo shale were sent to Dr. Vaughan, who pronounced them to be of Oligocene age. The shale seems to represent at least a part of the group referred to in the Carmen-Zambrano section, which can be followed northeastward from Carmen to San Jacinto and San Juan.

The author has no positive evidence that the Oligocene is oil-bearing in Colombia, though Arnold has stated that the oil of Colombia probably originated in Cretaceous and Oligocene strata.

MIOCENE SERIES

The Miocene strata of Colombia occur, as do the Eocene, in three distinct facies, marine, estuarine, and fresh water. In the districts along the north coast they are entirely marine, whereas in the valley of the Magdalena above El Banco they become only partly so, or at least not prominently marine. In the upper valley of Magdalena River and on the plateau they are entirely non-marine.

Marine Miocene rocks are widely distributed along the north

[1] Arnold, *Econ. Geol.*, Vol. 11 (1916), pp. 299–326.

[2] Beck, *Econ. Geol.*, Vol. 16 (1921), No. 7, p. 465.

coast of Colombia, from near Rio Hacha to the Gulf of Urabá, and they extend inland along the valley of the Magdalena at least as far as El Banco and to an unknown distance into the valleys of the Rio San Jorge, Rio Cesar, and the Rio Sinú. In this latter valley they are found above Montería and about San Andres and eastward on the drainage of the San Jorge, possibly connecting with the Miocene of the west coast, where they are reported by Bossler.[1]

In the north coastal districts the series is well represented by the Tubera-Usiacurí groups, consisting of clay shale, sandy shale, and sandstones, each in thick bodies, aggregating on the whole not less than 3,500 feet. The lower group contains numerous species of foraminifera and the sandstones at the top, an abundant fauna of marine molluscs of Middle or Lower Miocene age. These are abundant in all the districts along the north coast, especially at the two localities named.

In the purely non-marine facies of the interior no determinative molluscan fauna has been found, and while the age may be inferred from stratigraphic relations, it is also corroborated from fossil plants found in several far-separated districts, as described by E. W. Berry.[2]

In the upper valley of Magdalena River the beds are largely conglomerate and pebbly sandstone, entirely detrital in character, and in some places, they attain a thickness of more than 3,000 feet. The series is well exposed along the river just above Honda, also south of Tocaima and between Chicoral and Gualanday on both sides of the Rio Coello. The series has been described by Scheibe,[3] who proposed for it the name of Barzalosa beds. Berry[4] has mentioned floras of Miocene age from Santa Ana, above Mariquita, and at Leiva, and perhaps at other places on the plateau, without, however, giving any description of the strata in which they occur.

Except for foraminifera in the lower shales of the marine facies, and the molluscs of the upper member, the Miocene strata are almost without any organic content. Certainly there are no thick strata of

[1] Huntley and Mason, *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 68 (1922), p. 1018.

[2] E. W. Berry, *Bulletin of the Geological Society of America*, Vol. 35 (1924), p. 782.

[3] R. Scheibe, *Doc. de la Com. Sci. Nac. No. 2, Bogotá* (1922).

[4] Berry, *op. cit.*

organic nature that can be pointed to as a possible source of petroleum. The Miocene strata are of interest to oil men only from the viewpoint of association or of structure. They are not markedly unconformable upon the strata of the Lower Tertiary, and their structure may often be taken as indicating that of the underlying Tertiary formations.

Structures of the Miocene.—In the highly folded districts of Tertiary rocks, as about the Sinú Valley, the Miocene strata are usually

FIG. 7.—Sandstone saturated with asphaltic oil, near Chaparral, Barzalosa beds. Photograph by K. D. White.

involved with the older Tertiary series in various foldings and faultings, thus producing alternating zones of both. In other districts, where folding is gentler, Miocene strata are thrown into long folds, along which no Lower Tertiary may appear at the surface, as is the case in the anticline extending from near Puerto Colombia, southward to Usiacuri, Repelon, and Arenal for a total distance of nearly 50 miles. At the north faulting has disclosed evidences of oil and also of underlying older Tertiary strata which do not appear at other points along its course. At intervals are gas springs, active or extinct, which probably arise from underlying Lower Tertiary beds, the structural conditions of which may only be inferred from those of the Miocene. Other anticlinal folds occur in the Miocene farther east.

The structural conditions of the Miocene (Oponcito) series in the district of the lower Sogamoso have been mentioned. Some of the large deposits of asphalt found in this district appear to have a surficial position upon strata of the Oponcito series, but it does not necessarily follow that they are primarily derived from these rocks.

In the upper valley of the Magdalena, as at Honda and southward, the Miocene (Barzalosa) beds are usually faulted, producing a strong easterly dip at angles of 30 to 40 degrees. Farther south, and on the west side of the valley, structural conditions are different. Near Chicoral and southward the strike of these beds is north to south, and the dip is at first westward as much as 40 degrees. Farther west there follows a succession of folds in this series in which the underlying Guaduas beds are doubtless involved. The oil seeps and bituminous sand found in the Barzalosa beds of this district (Fig. 7) probably had their origin in the underlying Guaduas.

PLIOCENE SERIES

Like the two preceding series, the Pliocene rocks of Colombia occur in at least two distinct facies, marine and non-marine, but are of interest to oil men only from the fact that they sometimes carry evidences of petroleum such as bituminous sand, asphaltic seeps etc., if not also some secondary deposits of oil of commercial magnitude.

In the coastal districts near the Caribbean there are sandy shale, sandstone with corals, and elevated coral reefs fringing the coasts at intervals from the Gulf of Uraba to the Goajiro peninsula. In the near neighborhood of Barranquilla and Cartagena they are represented by the Galapa and La Popa groups respectively, and farther southwest, by the Escondido group. Their greatest thickness probably does not exceed 1,000 feet. They are doubtless the continuation of the Pliocene beds found on the shores of Limon Bay, near Colon, Panama.

How far they extend inland along the valleys of the Magdalena, Cesar, and San Jorge rivers is not known, though beds exposed on the river at El Banco seem to belong with this series.

In the upper valley of the Magdalena, at Honda and above, there are deposits of about the same thickness to which the name "Honda

beds" was applied by Hettner.[1] He also included older beds upon which the Honda group lies unconformably, now known as the Barzalosa beds. After much confusion and discussion it has become fairly settled that the two groups are distinct and, for the most part, of very different origin.

Both are well represented in the immediate vicinity of Honda, the older occurring on the river above Honda and eastward, and the later extending along Guali River west from Honda.

The Honda beds consist of nearly horizontally stratified sandstone conglomerate, and beds of andesitic tuff not exceeding 800 feet in aggregate thickness, resting inconformably upon the olded, generally eastward-dipping beds of the Barzalosa group, or upon still older rocks. They fill the valley of the Upper Magdalena between Honda and Mariquita, and extend from here southward, chiefly along the west side of the river as far as Coello or beyond. They can be followed also northward along the river to Puerto Berrio or farther, but their lateral extent is unknown.

Regarding the age of the Honda beds there is no direct evidence from either plant or animal remains, as far as known. Their stratigraphic relations to the Barzalosa beds at Honda and at other points farther south suggest a decidedly later epoch, presumably Pliocene, and their correlation with the marine Pliocene beds of the north coast districts is inferential.

Along the upper valley of the Magdalena, both above and below Honda, bituminous sands and asphaltic seeps are found in the Honda group, some of which are impressive. A good example of this is to be seen near the village of Mariquita (Fig. 8) and at other points farther south on the west side of the river. The seeps near Chaparral are believed to be connected with the Honda beds of this locality.

In the coastal districts, also, seeps of asphaltic oil, springs of sulphurous water carrying a little oil, and gas are found issuing from Pliocene rocks, though probably they arise from underlying older Tertiary beds. Here, too, in some places similar seeps are found coming from the beach sand, recent alluvium, gravel, and soil, but such deposits cannot be the primary source of these effusions.

[1] Hettner, *Die Kordillere von Bogotá* (1892), p. 15.

CONCLUSIONS

The commercial deposits of oil thus far developed in Colombia are not only actually found in Tertiary rocks, but both presumably and by evidence it originated in these rocks. There can be no doubt,

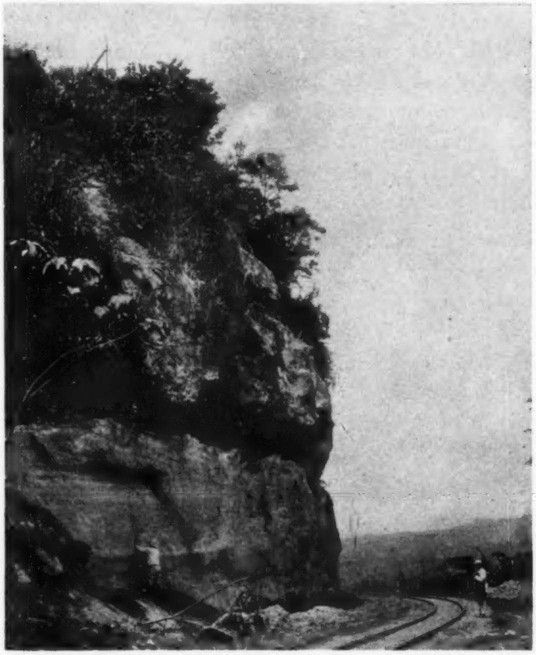


FIG. 8.—Asphaltic sand 12 feet in thickness at base of Honda beds, 6 miles south of Mariquita, upper valley of Magdalena River, Colombia.

that other deposits of commercial value will ultimately be found in these strata, not only in the districts of the Magdalena, but in others where similar conditions, not rare in Colombia, are found.

No deposits of petroleum of commercial proportions have yet been found in any Cretaceous area of Colombia at places where Tertiary strata do not exist; nor in Venezuela, if we may trust reports, are the strata of the Cretaceous extensively productive,

though in both countries they are known to be bituminous. Most of the so-called "bituminous limestone" of Colombia is bituminous only by courtesy and only in the sense that oil shale is bituminous. From most of the rock called "bituminous" no oil can be extracted by solvents, and if oil can be obtained from it at all it must be done by distillation.

In the somewhat rare cases in which petroleum really issues from rocks of the Villeta group it is in small quantities, not such as should constitute a basis for the belief that this group may be the source of the petroleum, and that it migrated into the porous sandstones of the Tertiary. If the view that "probably all the oil in Colombia has emanated from the Villeta group" is really sound it should be supported by better evidence than any yet given, and it appears very improbable that such evidence can be found.

OIL MINING

EDWARD BLOESCH
Tulsa, Oklahoma

ABSTRACT

This paper deals with the amount of oil left underground and methods of increasing recovery, deals with the geology, operations, and economic results of different oil mining enterprises, especially those visited by the writer, including oil tunnels of Sulphur Mountain, California, and the oil mines of Pechelbronn, Alsace, and Wietze, Germany. It considers methods of mining under different conditions and deals with the economic aspect of oil mining together with the possibility of developing it as an industry.

INTRODUCTION

While producing oil by pumping it from drill holes is a branch of mining, this paper treats only of producing oil by mining methods similar to those used for mining ores or coal.

It is well known, that the method generally used of producing oil by drilling of wells and pumping the oil from the ground does not exhaust the deposit. The percentage of oil taken out naturally varies considerably, but is hardly ever over 50 per cent of the oil originally contained in the sand. J. O. Lewis in his paper on methods for increasing oil recovery[1] estimates, that only 10 to 20 per cent of the oil ordinarily is extracted." Similar views have recently been expressed by Heald[2] who writes of a field where at least 175,000,000 barrels of oil are present in the oil sands and where it is believed that present methods of extraction will obtain less than 7,000,000 barrels.

Inasmuch as the world's supply of oil is limited and the consumption of oil products steadily increases, a shortage is likely to occur in the not very distant future. The amount of oil left in the ground is, therefore, a matter of great interest and practical methods for its recovery are of great importance.

Several methods are in use which increase the recovery of oil,

[1] J. O. Lewis, "Methods for Increasing the Recovery from Oil Sands," *U. S. Bureau of Mines, Bull. 148*, 1917.

[2] K. C. Heald, "Eighty Per Cent of Oil Not Recovered," *Oil and Gas Journal*, Vol. 22, No. 21 (1923), p. 58.

but their advantages and disadvantages are still open to discussion. As far as ultimate recovery is concerned, some of them are probably harmful. Several methods may be mentioned. Conserving the gas pressure by pinching in flowing wells is certainly beneficial, but should be done on all wells in a common pool. The uncertainties of this procedure are best illustrated by the fact that some producers find it more economical to drill up a new field as quickly as possible and to get as much oil as possible above ground while the gas pressure lasts, while others advocate a slow drilling campaign. The original natural gas pressure has been restored by compressed air, which method is reported as very successful in certain areas. The yield of pumping wells is often increased by applying vacuum. This method has been successful in many fields, but its advantage as to ultimate recovery is doubtful. Flooding of the oil sand has led to large recoveries in the Bradford field in Pennsylvania, but since probably 70 per cent of the original oil content is left in the Bradford sand after flooding,[1] this process leaves much to be desired. Scientific spacing of wells is helpful, but can seldom be done on account of property lines. Close drilling increases the recovery, but is uneconomical, especially in case of deep and expensive wells, as has been proved by numerous town site developments.

Complete recovery of the oil in a deposit can be accomplished only by mining the rock containing the oil, crushing or grinding up the rock as far as necessary, and extracting the oil either by heat (distillation), by a washing process, or with a solvent. Oil might thus be produced from oil shale, where valuable by-products would help pay the expense, and from certain coals (lignite), where the oils represent a by-product. Working oil-bearing sandstones or limestones in this way would seldom pay under present conditions. Oil thus produced could not ordinarily compete with coal at present, because at least five times the volume of rock must be mined in order to get the same volume of fuel. This is not now compensated for by the higher fuel value of oil. This method of producing oil will only be economical after crude oil gets sufficiently scarce as to make its special properties very valuable. This condition will arrive earlier

[1] Robert B. Bossler, "Oil Fields Rejuvenated," *Penn. Bureau Top. Geol. Surv., Bull. 56*, 1922.

in territories where the production of both coal and oil is very small compared with the demand.

Under present conditions in the petroleum industry certain mining methods can be used profitably and are, indeed, already used, which allow a much larger recovery than the well pumping method, but which do not extract all the oil contained in the sand. These are the methods used at Pechelbronn, Alsace, and methods based on the Pechelbronn system.

OIL MINES

Recovery of oil by mining operations has been resorted to for a long time, in fact it is older than the drilling of wells.

SHAFTS

Oil was produced in the early days by digging shafts into which the oil seeped and was brought to the surface. This method was used to a considerable extent in the oil fields of Europe and Asia and has not been fully replaced by modern drilling methods. Some of the shafts in Roumania are from several hundred up to a thousand feet deep.

TUNNELS

Oil has also been produced by driving tunnels into the mountainside, especially in the western part of the United States. Most of these tunnels are in California and are shown in part on blue prints of the California oil fields published by the California State Mining Bureau. A similar tunnel is also in operation near the Utah line in Colorado.[1]

The California oil tunnels are mostly located on the south side of Sulphur Mountain in Ventura County. Structurally this mountain forms part of an overthrust.[2] The oil is in the Monterey shale, which is strongly folded and dips steeply, in places 70° to 80°. The oil-bearing horizons crop out on the mountainside, but are mostly sealed by asphalt. The tunnels are driven from the valleys at a slight upward angle, sufficient to let the oil flow to the mouth. The length

[1] W. H. Emmons, *Geology of Petroleum*, 1921, p. 434.

[2] Max Reinhard, "Interprétation tectonique de la région pétrolifère de la vallée de Santa Clara en Californie," *Arch. Sciences phys. nat.*, Période 5, Vol. 1, 1919; N. L. Taliaferro, "Notes on the Geology of Ventura County, California," *Bull. Amer. Assoc. Petr. Geol.*, Vol. 8, 1924.

of the tunnels varies considerably. The writer has seen one in Coche Canyon only 12 feet long, while one in Adams Canyon is reported to be 1,900 feet long. Several of these tunnels are over 50 years old and are in part still producing. The different tunnels do not produce from the same stratigraphic horizon in the Monterey shale. In all, 31 tunnels were dug on Sulphur Mountain, the first one in 1866[1]. A tunnel in Toro Canyon, east of Santa Barbara, produced oil and water from the Tejon formation (Eocene). When some nearby wells were abandoned, the pipe line was used to irrigate with the water from the tunnel, but it is making enough oil yet (1921), that the latter has to be separated from the water. The oil tunnels in California are operated in conjunction with drilled wells. While most of the tunnels have produced enough oil to pay for their digging and operating, the output is too small to pay for general expenses like road and pipeline building, tankage, etc.

Oil sand has been mined by tunnels and also by shafts near Geneva, Switzerland, and heavy oil has been extracted from the sand.[2]

The exploitations near Gabian in Southern France, which date back to the earliest part of the seventeenth century,[3] were carried on by tunnels, started from shallow pits. They lead us to real mines, consisting of shafts and galleries. Gabian is the place, where recent drilling resulted in completion of a commercial well in November, 1924, opening up a new field for France.[4]

MODERN OIL MINING

In the last few years shafts and tunnels have been combined and modern mines have been opened for the production of oil. Two such mines are on a commercial basis, one at Pechelbronn, Alsace, the other one at Wietze, in Hannover, Germany.

[1] W. W. Orcutt, "Early Oil Development in California," *Bull. Amer. Assoc. Petr. Geol.*, Vol. 8 (1924), p. 64.

[2] Arnold Heim and Adolf Hartmann, "Untersuchungen über die petrolführende Molasse der Schweiz," *Beitr. zur Geologie der Schweiz*, "Geotechn. Serie 6," 1919.

[3] Paul de Chambrier, "Étude économique sur l'exploitation du pétrole par drainage souterrain," *Chimie et Industrie* (May, 1923). (Abridged translation published in *Journ. Inst. Petr. Techn.*, Vol. 9, 1923.)

[4] Sidney Powers, "Oil Well in Southern France, *Bull. Amer. Assoc. Petr. Geol.*, Vol. 9, 1925."

PECHELBRONN

The oil field of Pechelbronn, the only important producing field of France, is located in northern Alsace north of Hagenau in the valley of the Rhine. Structurally this valley represents a down-faulted trough or *graben* between the Vosges Mountains and the Black Forest. This *graben* is about 200 miles long and 15 to 30 miles wide with a maximum downthrow of probably 10,000 feet. It was formed mostly in Oligocene time, but movements occurred as late as the Pleistocene, which diverted the Rhine from its old course toward the Rhône and the Mediterranean to its present course[1]. In the mountains on the sides of the *graben* the sediments down to lower Triassic are practically all eroded and over large areas the crystalline basement forms the surface. In the Rhine Valley, Mesozoic and Tertiary sediments are present, but they are mostly concealed by terrace gravels, loess, and alluvium. The valley is bordered on each side by a major fault, but a number of minor faults, more or less parallel to the main faults, are present. East and west of the two main faults the strata dip away from the valley, but the general dip inside the *graben* is toward its center.

At Pechelbronn the strata dip southeast at the rate of 2° to 8°. The accumulation of the oil is due partly to the minor faults mentioned, partly to lenticularity of the sands.

The oil occurs in sands in different members of the Oligocene, which is partly marine, partly of brackish and fresh water origin. The Oligocene of this area has a thickness of over 4,000 feet and contains at least 13 pay sands.[2] These sands are all lenticular, but the lower ones are as a rule more extensive and regular than the upper ones. The sand lenses usually have their main extension in a northeast-southwest direction, parallel to the old shore lines and to the fault system.

An oil spring at Pechelbronn was known and utilized in the fifteenth century)[3]. Exploitation started in 1735, when a tunnel dug

[1] Edward Bloesch, "Zur Tektonik des schweizerischen Tafeljura," *N. Jahrbuch f. Mineralogie, etc.*, Beil.-Bd. 29 (1910), p. 640.

[2] M. Gignoux and C. Hoffmann, "Le bassin pétrolifère de Péchelbronn," *Bull. du Service de la Carte géol. d'Alsace et de Lorraine*, tome 1 (1920), No. 1.

[3] Hans Hoefer, *Das Erdoel und seine Verwandten*, 4th ed., 1922, p. 27.

in the hill side found the oil sand, which was mined and from which a heavy, tar-like oil was washed out. In 1745 a shaft was sunk, followed by others, from which galleries were driven into the oil sand and the sand was mined in the same way as a coal seam.

At first shallow sands occurring at a depth of about 30 feet were exploited, but later on deeper sands were attacked, which contained slightly lighter oil. In 1866 workings about 250 feet deep encountered oil, which was sufficiently light to ooze into the galleries. From then on the sand was not treated any more, as it was cheaper to use the oil seeping into the mine. Thus 1,000 tons of oil were produced in 1880.

As the mines had no ventilating system, accidents occurred, which led to a change in the method of mining. The main galleries were located above the oil sands and the producing horizons reached from these galleries by means of slopes, these workings being about 300 feet deep. Oil was produced in this manner from 1875 to 1888.

In order to lay out properly the plans for future mining operations, test holes were resorted to, which also helped to avoid gas and water troubles and heaving sands. In 1882 one of these test holes at a depth of 139 meters encountered oil of higher gravity, which to the surprise of the drillers flowed to the surface. Subsequently the field was exploited by wells as in other fields and mining was given up in 1888. The depth of the wells varies from 100 to 600 meters (300–2,000 feet).[1]

The world-war created a big demand for oil and its products, but in the meantime the production of the Pechelbronn field had dropped to where a good many wells could hardly be operated at a profit and new drilling gave only partly satisfactory results. Under these circumstances the old mining methods were recalled, after experiments conducted by P. de Chambrier had proved that a considerable amount of oil was left in the sands even after the wells had been pumped nearly dry. Accordingly, it was decided to mine the sand and extract the balance of the oil. A shaft, 500 feet deep, was completed in 1917 in a practically exhausted part of the field and galleries were driven into the oil sand.

[1] Paul de Chambrier, "Les Gisements de Pétrole d'Alsace," *Soc. d'Encouragement pour l'industrie nationale, Bull.* (Janvier–Février, 1920), p. 21.

The results were surprising. It was found that not only all the oil which had been expected was actually present in the sand, but that the oil flowed or seeped into the underground workings in sufficient quantity to make it unnecessary to mine and wash the sand. Therefore, instead of mining and washing the sand, the galleries were extended to form more drainage channels. What is often done in wells by mechanical devices or by shooting to enlarge the producing surface and to create a fresh sand surface had been accomplished on a large scale by mining. Instead of having, say, the circumference of a 6-inch hole for the thickness of the sand or eventually the surface of a shot hole, they had created a sand surface, which could be enlarged at will by lengthening the galleries or by digging new ones. Thus this mine produced 18,200 tons of crude oil in 1918,[1] the first full year the mine was in operation. Already in 1917 the success had led to the starting of a second shaft.

On fresh surfaces the oil oozes out the full height of the gallery, or the full height of the exposed oil sand, but the oil level on the face drops and soon only the lowest part produces. Therefore, the tunnels are extended slowly but continuously, most of the production coming from fresh faces. The oil is conducted to central sumps from which it is pumped to the surface. Drifts are usually made 50–100 meters (170–330 feet) apart and cross-cuts every 50 meters (170 feet).[2]

At the close of 1924, three mines were in operation at Pechelbronn with 5 shafts, 150–250 meters (500–800 feet) deep. Another shaft under construction is going to be carried to about 1,000 feet. Two of these mines produce from two different horizons 50 meters (170 feet) apart. Most of the work has been done in the first mine.[3] Altogether about 20 miles of galleries have been dug and 170,000 tons of crude oil have been produced.[4]

[1] M. Langrogne, "Notice sur l'exploitation par puits et galeries des gisements pétroliferès," *Annales des Mines* (Avril, 1921), p. 14.

[2] Paul de Chambrier, "Les mines de pétrole de Péchelbronn," *Conférence faite à Mulhouse à la société industrielle,* 1920, p. 24.

[3] See plan: C. Schlumberger, "Technique de l'exploitation minière à Péchelbronn," *Chimie et Industrie* (May, 1923), Fig. 4.

[4] Paul de Chambrier, personal communication.

The figures in Table I show the production in tons (about 7 bbls. to the ton) of the Pechelbronn field for the years during which the mines were in operation and for a few preceding years.

The mines at Pechelbronn have produced over one million barrels of oil and for the last two years the daily production has been about 700 barrels. The decrease in mine production from 1919 to 1921 is partly due to the disturbed economic conditions of the post-war

TABLE I

PRODUCTION OF CRUDE OIL AT PECHELBRONN

	From Wells	From Mines	Total of Field
1913	49,560	0	49,560
1914	48,960	0	48,960
1915	43,200	0	43,200
1916	41,520	0	41,520
1917	39,100	7,700	46,800
1918	30,886	19,154	50,040
1919	30,000	17,160 (est.)	47,160
1920	42,160	12,800	54,960
1921	43,825	11,750	55,575
1922	45,150	24,960	70,110
1923	33,226	37,469	70,695
1924	32,356	38,513	70,869
Total	....	169,504 tons*	....

* This total and all the figures for 1921 to 1924 are from personal communication by Mr. Paul de Chambrier to whom the writer is under great obligation, the other totals are from M. Schlumberger (*op. cit.*, Fig. 7), the mine production from 1917 to 1919 from M. Langrogne (*op. cit.*, p. 14), and the other data are figured by the writer from the totals.

period, partly to accidents, which necessitated shutting down part of the mine.[1] For the last three years the total production of the field has been about the same and equal to the capacity of the refinery at Pechelbronn.[2] In mining operations production can be regulated much more easily than in producing oil from wells.

Of particular interest is the large quantity of oil produced from a sand which was nearly exhausted by wells. It was determined that from the oil originally contained in the sand 17 per cent was pumped out through the wells, that an additional 43 per cent was recoverable through the seeps in the galleries and 32 per cent more by

[1] M. Langrogne, *op. cit.*, p. 17.

[2] Paul de Chambrier, "Les mines et la raffinerie de Péchelbronn," *Conférence faite à l'institut de chimie de l'université de Strasbourg*, 1920, p. 25.

washing the sand, while 8 per cent is a loss.[1] Actual figures are: Area of shaft No. 1: 4 wells produced in 1908–17, 21,000 tons; mine produced in 1917–20, 48,000 tons.[2]

The oil sand dug out in constructing the galleries is piled up in dumps from which some seepage oil is collected, and it is intended later to extract the balance of the oil. Experiments have led to the development of a practical method of washing the sand, but as it barely pays, the necessary installations have not been made yet.

While the different oil sands vary in thickness from a few inches up to 5 meters (17 feet),[3] the sands actually mined have a thickness of 1.8–3 meters (6–10 feet). They are not cemented and therefore are easy to mine. The only difficulties in mining at Pechelbronn consist of danger due to gas and gasoline vapors. Some recently adopted changes in the working methods at Pechelbronn will be described below.

Descriptions of the mines at Pechelbronn including a map of the workings of mine No. 1 have been published by De Chambrier,[4] former general manager of the Pechelbronn works and by Schlumberger,[5] French chief engineer of mines. Maps of the whole field have been published by De Chambrier[6] and by Gignoux et Hoffmann.[7] A complete account of the history of Pechelbronn is given by De Chambrier.[8]

WIETZE

The success of mining oil at Pechelbronn led to the construction of a similar mine in the old oil field of Wietze near Hannover, Germany. This oil field is located on the northwest flank of a salt dome and has a very complicated structure.[9] Under a nearly horizontal

[1] *Ibid.*, "Étude économique, etc.," p. 5.

[2] *Ibid.*, "Exploitation du pétrole par puits et galeries," 1921, p. 21.

[3] C. Schlumberger, *op. cit.*, p. 2.

[4] Paul de Chambrier, "Exploitation, etc."

[5] C. Schlumberger, *op. cit.*

[6] Paul de Chambrier, "Les gisements, etc.," pp. 16–17.

[7] M. Gignoux et C. Hoffmann, *op. cit.*, Pl. 1.

[8] Paul de Chambrier, "Historique de Péchelbronn," 1919.

[9] Alfred Kraiss, "Geologische Untersuchungen über das Ölgebiet von Wietze in der Lüneburger Heide," *Köenigl. Preuss. geol. Landesanstalt, Archiv für Lagerstättenforschung*, Heft 23, 1916.

cover of Pleistocene, Tertiary, and youngest Cretaceous, there is found a series comprising middle Jurassic to lower Cretaceous dipping steeply, 60–70°, away from the salt core. This structural unit is thrust on a fault plane toward the north over another series of similarly dipping strata comprising upper Trias and lower Jurassic. The salt is of Permian age, as strata belonging to this period have been folded up with it. Both of the above-mentioned structural units contain a large number of faults belonging to two systems, one longitudinal, the other transverse. The longitudinal faults (strike faults) are evidently younger than the overthrust movement, as none of them is known to traverse the overthrust plane and some can be traced westward into the Tertiary. The transverse faults are independent above and below the overthrust plane and are evidently caused by differential pushing movements during the formation of the overthrust. Similar faults in the upper Cretaceous indicate movements along the transverse fault system after deposition of this formation, but only slight movements on some of these faults are noticeable in the Tertiary.

Thus the whole area consists of a large number of fault blocks, making the structural conditions of the oil field exceedingly complicated. The leading factor in the oil accumulation is the steep dip away from the salt core, the reservoirs being sealed partly by faults, partly by overlapping impervious strata.

The oldest oil-producing horizon is the uppermost Trias, which contains light oil at a depth of a little over 1,000 feet. Light oil occurs only below the overthrust, while above the oil is heavier. There the middle Jurassic and upper Jurassic are producing, also the Purbeck and Wealden (uppermost Jurassic and lowermost Cretaceous). All of these oil horizons are sandstones except the one in the Wealden, which is a loose sand, and wells producing from it have to be bailed, because the floating sand interferes with successful pumping. Some oil has migrated from the steeply dipping sands into the overlying strata. The unconformable upper Cretaceous yields oil but the Tertiary only shows traces of oil and gas. These younger formations have acted as an impervious cap rock and kept the oil from seeping out, except in a few places very near the salt dome, where secondary asphaltic oil has accumulated in Pleistocene sands and was exploited long before any oil wells had been drilled.

Mining operations at Wietze encountered much trouble on account of heaving beds, which threatened to close the galleries. This necessitates extra heavy timbering and even masonry. The first shaft, which started to produce in 1920, is 250 meters (800 feet) deep, oil sands at 220 and 250 meters depth being worked.[1] According to last reports the present monthly production is between 1,000 and 1,200 tons.

From the oil originally contained in the sand about 25 per cent is said to be recovered by wells and 61 per cent by mine drainage. The mined sand is also treated and additional oil recovered from it by a washing process. These percentages are hardly very accurate, since the sand volumes of a certain area cannot be figured accurately owing to the complicated structural conditions.

On account of structural complications and still more on account of the heaving formations, mining at Wietze is very expensive. While no figures as to costs and economic results are available, the latter are evidently satisfactory, as can be judged from the fact, that a second shaft has been put down and is now in operation.

OTHER MINES

In several other places mines have been started, with the intention to produce oil by the method so successfully used at Pechelbronn. A shaft was sunk at Heide, northwest of Hamburg, where the oil is contained in a chalk of Upper Cretaceous age. This rock would not give up the oil as the sands do and the oil must be separated by distillation. A plant for this purpose is reported to be in process of erection, but it has not yet reached the producing stage.

Oil mining has been undertaken on a small scale in Roumania,[2] but according to available reports the installations were not sufficient to cope with conditions arising in a large mining operation of this nature.

A small oil mine using the Pechelbronn system is also reported from the Baku district in Russia.[3]

[1] Charles Camsell and Arthur Buisson, "Petroleum Mines," *Canadian Mining Journal*, April 11, 1924.

[2] I. P. Voiteşti, "Notiuni de geologia petrolului," *Revista muzeului geol.-miner. al universitatii din Cluj*, Vol. 1, No. 1, p. 40.

[3] *The Oil and Gas Journal*, Vol. 22, No. 26, p. 56.

In the Athabaska district of Canada a shaft was sunk to a depth of 40 feet in order to produce oil from the tar sands by means of mine drainage, but the heavy oil would not seep in to the mine.[1]

So far as known to the writer the only mine in the United States which operates in oil-bearing rocks is at Ravenna, Estill County, Kentucky.[2] A shaft was sunk 130 feet deep to the top of the Onondaga (Coniferous) limestone, which is the oil-producing rock in this field and the shaft produced 5 barrels a day for about a year.[3] Later the opening in the limestone was widened and holes were drilled horizontally into the oil rock in order to increase the production. No information on the results is available. This undertaking seems more experimental than commercial. Since the oil is found in cavities of a limestone, the conditions are very different from those encountered in the European oil mines.

According to a recent newspaper report a shaft started at Newport Beach, California, has reached the oil sand.

DIFFERENT MINING METHODS

Both the mines at Pechelbronn and at Wietze produce oil which is high in lubricants and low in gasoline. The Pechelbronn oil is 31 degrees Bé.[4] and contains about 4 per cent gasoline,[5] while the Wietze oil is of 19 degrees Bé. and furnishes only 1 per cent of gaso line.[6] Therefore, in these mines there is little gas and not much gasoline vapor, which makes it possible to keep the mines well ventilated and thus to reduce the fire and explosion hazard to a minimum. Two serious accidents have occurred at Pechelbronn,[7] but with elaborate safety devices, partly installed after these accidents had furnished experience, the management feels able to cope with these dangers.

[1] *The Oil and Gas Journal*, Vol. 23, No. 21-*A*, p. 104.

[2] Willard Rouse Jillson, "A New Method of Producing Crude Oil in Kentucky," *Kentucky Geol. Surv.*, Ser. 6, Vol. 6 (1921), p. 149.

[3] John McMinn, personal communication.

[4] Paul de Chambrier, "Draining Oil Reservoirs by Shafts and Tunnels," *Engineering and Mining Jour.*, Vol. 112, No. 3, 1921.

[5] Paul de Chambrier, "Étude économique, etc.," p. 8.

[6] Charles Camsell and Arthur Buisson, *op. cit.*

[7] M. Lagrogne, *op. cit.*, p. 14.

Up to the end of 1922 five men had been killed underground at Pechelbronn,[1] but only two of these deaths were due to accidents peculiar to oil mining. The death rate averages one death to 60,000 working days,[2] which is about equal to the underground death rate in the coal mines of the United States.[3]

Most of the oil deposits of the world contain more gas and especially more gasoline and would be more dangerous to mine than the deposit at Pechelbronn. Proper ventilation might be too expensive if possible at all, and a considerable part of the light products might be lost on account of evaporation. Therefore, engineers have given much attention to means to avoid or minimize the dangers. Many improvements have been made in the Pechelbronn mines in ventilating, lighting, in carrying on the underground work and in handling the seepage oil.

The working method used at Pechelbronn from 1875 to 1888 indicated that the main galleries might be located to advantage outside of the oil sand. This suggestion was made by Langrogne[4] and recently put into operation at Pechelbronn. These new galleries are located above the oil sand and the oil is drained by slits cut into the oil horizon, which are covered up, so that not so much gas gets into the galleries. The gasoline vapors being heavy will mostly stay below the covers. Rich has patented such a process in the United States,[5] the patent covering also the application of fluids (water, steam, air, gas, etc.) through wells drilled inside of blocks or pillars surrounded by channels or galleries.

A process worked out by Ehrat, who has been connected with oil mining for years, is based on a different principle. The galleries are dug entirely outside of the oil sand above or preferably below, or both, or on the side, if the dip is steep, and the sand is tapped by shallow drill holes spaced at short intervals. These wells are equipped

[1] C. Schlumberger, *op. cit.*, p. 14.

[2] Paul de Chambrier, "Les mines de pétrole, etc.," p. 28.

[3] William W. Adams, "Coal-mine Fatalities in the United States, 1923," *U. S. Bureau of Mines, Bull. 241*, 1924, Table 49.

[4] M. Langronge, *op. cit.*, p. 29.

[5] John L. Rich, "Process for Extracting Petroleum by Underground Workings," *U. S. Patent 1,507,717*, 1924.

with short casings or nipples set tight, so that the sand is completely sealed. Thus any pressure present in the oil-bearing rock can be fully utilized. After the wells cease to flow, other methods of getting production, like vacuum, compressed air, flooding, etc., can be used and these agencies can be regulated much better than can be done at present from the surface. Patents[1] for the Ehrat process have been granted or are pending in most of the oil-producing countries. The Ehrat process has not been sufficiently tried to permit final judgment as to its merits, but it seems to solve the problem of mining light oil.

During the early period of mining at Wietze, before the galleries had entered the oil sand, some oil was produced by tapping the sand from the mine by means of the drill.

At Pechelbronn sands occurring in the vicinity of the horizons mined by galleries, but too thin to pay for establishing a separate level, are drained by the Ehrat process.

Near Jacksboro, Texas, an experimental mine is in operation, which uses the Ranney process,[2] which is identical in principle with the one just described. The mine is claimed to be a success.

While running the galleries outside of the oil-bearing rock has a big advantage in high-grade oil fields and also in others where considerable gas or water is present, the Pechelbronn system is preferable, where it is expected later to mine the sand and extract the remaining oil.

ECONOMIC ASPECT OF OIL MINING

In the light of ultimate recovery, oil mining is a great improvement and it is merely a question of time as to when we will have to mine the oil-bearing rocks and extract the oil from the material brought to the surface.

At Pechelbronn, the only oil mine which has been in operation long enough to afford definite figures, mining of oil has proved to be a financial success. Figures on costs cannot be compared very well on account of economic conditions of the war and post-war time.

[1] Adolf Ehrat, "Improvements in or relating to the Recovery of Petroleum and Natural Gas," *British Patent No. 175,116*, 1922.

[2] Lawrence E. Smith, "New Method of Producing Oil Is Given First Test in Jacksboro Field," *Nat. Petr. News*, Vol. 16, No. 45 (1924), p. 63.

The cost of mining oil at Pechelbronn was about 30 per cent higher than the cost of producing oil by wells in the same field.[1] Experience has led to a reduction of mining costs and they are now supposed to be practically the same as the well costs. Under wartime conditions the first mine at Pechelbronn paid for itself with the production of the first three months.[2] It must also be remembered, that 17 per cent of the oil contained in the sand had already been pumped out through the wells.

The biggest saving of an oil mine compared with wells is in the lifting expenses, because in mining, the oil of a large area can be handled with one large pump.

Mining will have to be undertaken in many other places to determine its practicability and cost under various conditions. While the actual cost of producing oil by mining under different conditions, especially as they exist in the United States, cannot be determined yet, it compares favorably with the cost of producing oil out of shale. Under the most favorable conditions oil can be produced as cheaply if not more cheaply by mining as by wells, and oil mining is quite feasible under present conditions in the oil business.

While in developing an oil field by the drilling method a comparatively small investment furnishes quick results, pays for itself with flush production, and furnishes a small but steady income from settled production, oil mining requires a large investment at the start. The initial investment for a real oil mine may exceed one million dollars figuring on two shafts, all the machinery, pipe, tankage, buildings, road or railroad construction, etc., an amount, which is not unusual in other large industrial plants. There are no returns while the first shaft is being sunk and it may take two or three years to get operations in full swing. Income will start with the driving of the galleries, which can be constructed on the "pay as you go" plan. Production will increase until the largest part of the field is tapped, which means several years. From then on production will compare with settled production of wells. Large flush production endangering the market will not occur. In times of low market, production can be diminished by shutting down development and in

[1] C. Schlumberger, *op. cit.*, p. 16.

[2] Paul de Chambrier, "Les gisements, etc.," p. 23.

times of high market, the driving of the galleries can be pushed. This means, that a producer can sell a larger part of his production at a high price. If advisable, oil can be stored at very little expense in unused parts of the mine.

Mining is not only a method to obtain additional oil from exhausted or nearly exhausted fields, but should be used for the exploitation of virgin deposits adapted to this method. To develop them first by means of wells is an economic waste, inasmuch as mining will have to be resorted to in the long run. Only enough tests, preferably with a core drill, should be put down to determine the number, depth, and thickness of the sands and to outline the pool. Where the structure is known and sands are fairly regular, one well showing the water table in each sand is sufficient for determination of the productive area. Cores of the sand are necessary in order to determine the porosity and oil content of the rock, permitting one to ascertain whether mining is likely to pay or not.

ESSENTIAL CONDITIONS FOR OIL MINING

Oil mining should only be undertaken where sufficient oil to pay for a large investment can reasonably be expected. It is very important to know the gasoline content of the oil and the gas and water contents of the sand in order to decide whether the mining operations can be carried on in the sand or if the galleries shall be driven outside of the oil-bearing stratum. The depth should not be excessive. While the Pechelbronn mines are only 150–250 meters (500–800 feet) deep, depths of 2,000 or even 3,000 feet may not be prohibitive. Inasmuch as oil mining is still more or less in the experimental stage, shallower fields should be mined first, because initial expenses especially for the shafts increase with depth.

Of prime importance also is the size of the field or pool. If the area is too small, the sinking of a shaft does not pay. Because of the need for ventilation and as a safety measure, two shafts are preferable to one. In some countries two shafts are specified by the mining laws, but, of course, a shaft of large diameter could be divided into two sections which, with proper insulation, would be nearly as good as two separate shafts. Two shafts are sufficient for a field of several square miles, which is an area much in excess of the average oil

property in the United States. Therefore, owners of leases in a common pool ought to get together and operate a mine jointly.

Information about the rocks, through which the shafts must be sunk and about the oil sand can be obtained from old wells, providing proper records have been kept. Usually it will be necessary to drill a number of core drill holes to get the necessary information. It is important that abandoned holes have been properly plugged or are in a shape to be plugged; otherwise they may cause trouble. Plugging of abandoned wells and dry holes is compulsory in most places, but often the plugging laws have not been properly enforced. In old fields even the location of some of the holes is unknown. Some old wells could be used for ventilation, for pumping oil out of the mine, or for conveying compressed air or steam to the workings.

Present oil and mining laws devised for other purposes may be harmful to oil mining or at least may not give it sufficient protection. However, most government agencies are awake to the importance not only of developing, but also of conserving the oil resources. As oil mining is conservation in the highest sense of the word, the governments will certainly encourage it.

SUMMARY

As far as ultimate recovery is concerned, draining oil sands by mining methods is a great step forward and leads to the final step, namely mining of the oil rock and extracting the oil.

Economically, oil mining is a success at least in fields which are best suited for this method. Much experience leading to improvements will be gained as soon as mines are started under conditions different from the ones at Pechelbronn or Wietze.

Working underground in or near the oil-bearing rocks will furnish geologists much new information about origin and migration of oil and it is to be hoped that observations by competent men are carefully recorded and published for the benefit of science and the oil industry.

May, 1925

REFLECTED BURIED HILLS IN THE OIL FIELDS OF PERSIA, EGYPT, AND MEXICO[1]

SIDNEY POWERS
Amerada Petroleum Corporation, Tulsa, Oklahoma

ABSTRACT

Reflected buried hills are topographic highs on old land surfaces which are reflected in the superposed sedimentary deposits. They have been found by drilling in many of the oil fields of the Mid-Continent region where the presence of buried topographic features has been proved. Descriptions of buried hills in foreign oil fields, which perchance include examples of buried folds, form the subject of the present paper. It is hoped thus to call attention to the world-wide importance, both scientific and economic, of buried hills.

INTRODUCTION

Reflected buried hills, since recognition in the Healdton oil field, Oklahoma, in 1916, have become accepted as of great importance in oil accumulation. Oil is commonly produced from them or from overlying sedimentary rocks or from both. The ever increasing importance of petroleum deposits at unconformities and in buried folds and buried hills furnishes the incentive for this review of structural conditions connected with buried hills followed by descriptions of certain foreign oil fields where the presence of buried hills is suspected.

Adequate descriptions of structural conditions of oil fields are few and information available for this compilation is meager. Maidan-i-Naftun, the oil field of Persia, is on a surface anticline developed in strata which are probably unconformable with those at depth and it may be on a buried hill. Gemsah and Hurghada, the oil fields of Egypt, are on buried granite hills reflected in surface structure.

Mexico in the "Southern" fields furnishes an excellent example of buried structure which must represent an unconformity and, hence, a buried ridge. Portions of it were discovered because of superposed anticlinal structure.

Paucity of original ideas and the abundance of those of kind friends render the matter of scientific acknowledgments so difficult

[1] Manuscript received by the editor, February, 1926.

that one is prone to omit all, but the writer cannot refrain from expressing his gratitude to Mr. E. DeGolyer for stimulating this fruitful field of research.

DEFINITIONS

Buried hills are topographic highs on old land surfaces covered by younger sedimentary rocks (Fig. 1).[1] They have been found by drilling and mining operations in various portions of the world,[2] but have not received consideration except in the Mid-Continent oil fields where a considerable proportion of the oil accumulation is associated with them. Buried hills may be composed of igneous or sedimentary rocks and may have irregular surfaces. Where they consist of sedimentary rocks the structure of these rocks is usually difficult to decipher and may or may not be anticlinal.[3] Salt domes also give rise to buried hills.

Examples of buried hills are abundant in southeastern Kansas where ridges and hills of "Mississippi lime" formed islands in the Pennsylvanian sea during Cherokee time and sands which are called Bartlesville were deposited on their flanks and in the channels between them.[4] Foreign examples are not readily cited, but the published subsurface structure contour map of the Comodoro Rivadavia oil field of Argentina looks so similar to maps of portions of the Mid-Continent region that some relationship between sand conditions and contemporaneous relief is suggested.[5] In the Plaza Huincul oil

[1] Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Ec. Geol.*, Vol. 17, pp. 233–59, 1922. This definition of buried hills was suggested by W. B. Heroy, of New York City, whose valuable criticisms have clarified this paper.

[2] W. A. J. M. Van Waterschoot van der Gracht, "The Saline Domes of Northwestern Europe," *Southwestern (Am.) Assoc. of Petroleum Geologists, Bull.*, Vol. 1, 1917, pp. 85–89.

[3] E. M. Parks, "Migration of Oil and Water," *Am. Assoc. of Petroleum Geologists, Bull.*, Vol. 8 (1924), p. 705, proposes "reflected anticlines" for reflected buried hills which are anticlinal.

[4] H. A. Ley, "Subsurface Observations in Southeast Kansas," *Am. Assoc. Petroleum Geologists, Bull.*, Vol. 8 (1924), pp. 445–53.

[5] A. Windhausen, "Cambios en el Concepto de las Condiciones Geológicas del Yacimento Petrolífero de Comodoro Rivadavia," *Boletín de la Academia Nacional de Ciencias de Córdoba*, Vol. 27 (1923), pp. 1–8; "Lineas Generales de la Constitución Geológica de la Región Situado al Oeste del Gulfo de San Jorge," *ibid.*, 1924, pp. 167–320 (with bibliography, areal, geological, and structure contour maps).

field, Province of Neuquen, Argentina, and along this line of folding the possible presence of buried hills of Upper Jurassic (Kimmeridgian) age is interpreted from the meager published information.[1]

Buried hills partly uncovered by erosion have been called baraboos[2] from the Baraboo Hills of Wisconsin. Other examples are found in the porphyry ridges of the Ozark Mountains, the limestone hills around the Marathon Uplift, the granite knobs comprising the western end of the Wichita Mountains in Oklahoma and in the limestone Criner Hills and Mannsville partly exposed hill near the Arbuckle Mountains. Foreign examples are very numerous. Those in the southern half of the Orinoco Basin of Venezuela where hills of granite project through the Quaternary are worthy of notice because similar buried hills may be found farther north by drilling.

Reflected buried hills are those whose presence is indicated by anticlinal structure in the overlying sediments (Fig. 1, $A_{1,2}$). This is the common type, well known in the Mid-Continent region, as at Healdton. Reflected structure (Fig. 1, B_4) signifies that the structure above and below an unconformity is approximately superposed and parallel. Reflection of former topography in strata overlying buried hills is in many cases obscure owing to the low relief in the buried hills, to unconformities, or to thick overlying stratigraphic sections. Groups or lines of buried hills characterize large structural features such as the Cushing oil field of Oklahoma and the Nemaha Mountains (Granite Ridge) which extends for about 300 miles from northeastern Nebraska into Oklahoma.

Positive elements are those segments of the earth's crust which tend to rise with relation to adjacent segments. Anticlines are commonly positive and rise spasmodically or periodically with tectonic movements subsequent to their formation[3]—posthumous folding.[4]

[1] J. Keidel, "Sobre la Estructura Tectónica . . . . Neuquén," *Ministerio de agricultura, Publicación*, 8, 1925 (with bibliography); C. M. Hunter, "The Oil Fields of Argentina," *Inst. Petroleum Technologists, Jour.*, Vol. 10 (1924), pp. 829–53.

[2] F. H. Lahee, *Field Geology*, New York, 1916, p. 322.

[3] E. Haug (*Traité de Géologie*, Vol. 1 [Paris, 1912], p. 220) states the law of rejuvenated, superposed folding, first enunciated by Godwin Austin as follows: "If the direction of the orogenic force is exactly the same in the two phases of consecutive folding, the two systems of folding will be exactly superposed; they will have the same direction and the anticlines of the second generation will rise on top of those of the first."

[4] E. Suess (*The Face of the Earth*, Vol. 2 [London, 1906], p. 95) defines posthumous. He refers to the folds of Texas and Oklahoma as backfolds—folds back of the principal mountain system (Vol. 4 [1909], p. 512).

Topographic expression of gently folded anticlines is more commonly in the form of hills than valleys and this is one important reason for the relative abundance of anticlinal buried hills.

Reflection of a hill in sedimentary rocks deposited around and over it is primarily a matter of deposition, expressed in shortening of the section overlying the hill in direct proportion to its relief; and secondarily a matter of structure expressed in compacting and lithefaction of sediments with or without folding. Initial dips before compacting are not of great importance. Reflection of buried hills in case of no subsequent structural movement except compacting must die out upward gradually. Where there has been subsequent movement it commonly rejuvenates the buried hills because they are situated along lines of folding or relief and are usually anticlinal even where they consist of the granitic cores of anticlines. Reflection of topography is obscured by folding. "Reflected" buried hills, as the term has been used by the writer, could more accurately be changed to "refolded" (Fig. 1, A_4) and implies superposition irrespective of possible causal relationship of structure to topography. Differentiation between depositional and deformational structure in areas of gentle folding is in many cases impossible.

Buried hills and buried structure are not necessarily the same. Many examples of buried structure may be cited, such as the Big Lake field, Reagan County, Texas, where younger rocks not reflecting underlying folding conceal a buried anticline which was truncated, apparently without topographic expression before deposition of the later rocks. Differentiation between buried hills and mere buried structure must always be obscure where correlation and geologic history cannot be deciphered accurately from the record of well logs. Refolding adds complexity to this differentiation. To exaggerate the importance of buried hills and to describe many buried structural features as such is a natural error which may be found in this and other papers.

Modern examples of hills and ridges in process of being buried by marine sediments are abundant in the Pacific Ocean, especially on the continental shelf of North America as revealed by sonic soundings.

ORIGIN

The origin of mountain-building is one of the complex problems yet to be solved. Buried hills are minor geological features, but their

small size, general lack of sharp unconformities, irregular distribution, and inaccessibility causes their origin and subsequent rejuvenation to be added to the unsolved problems.

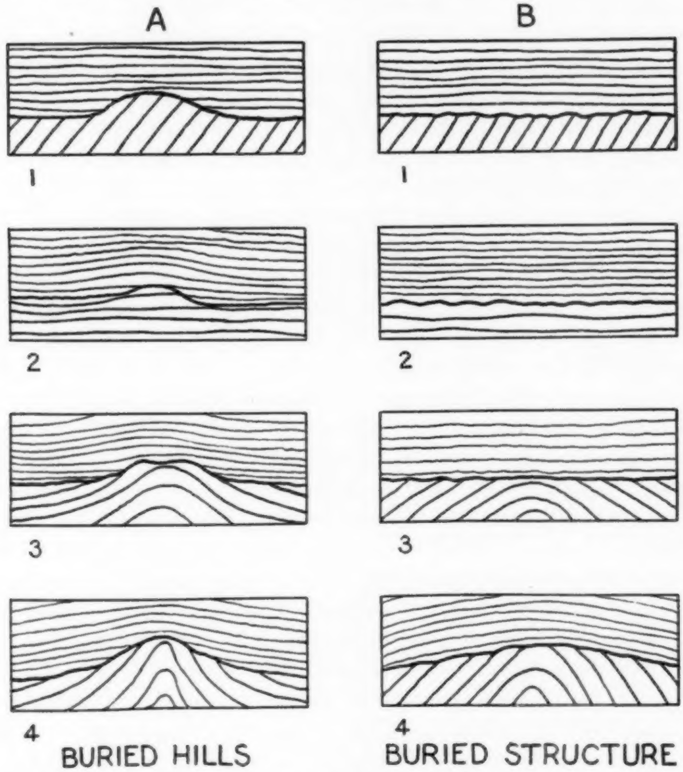


Fig. 1.—Ideal cross-sections illustrating the difference between buried hills (*A*) and buried structure (*B*). *A* 1, buried hill; *A* 2, buried hill, composed of horizontal strata, reflected in overlying strata; *A* 3, buried anticlinal hill reflected in overlying strata; *A* 4, refolded buried anticlinal hill which may or may not have been reflected before later folding. *B* 1, uncomformity; *B* 2, disconformity; *B* 3, buried anticlinal structure; *B* 4, refolded buried anticlinal structure.

Resistant topographic hills are common. The granite ridges in Egypt along the Red Sea are excellent examples and the same series of ridges is represented in the Egyptian buried hills with superposed

anticlines described below, the anticlinal form being caused by renewed regional tangential compression. Maidan-i-Naftun, in Persia, may be another example of a (dolomite) ridge covered by sedimentary rocks and subjected to regional tangential compression. Yet, not all hills are composed of resistant rock: drilling on the Gulf Coastal Plain in Texas has revealed buried hills of Miocene shale which may or may not be anticlinal.

Local uplift, periodic or gradual, with later sedimentation has affected the folds and buried hills of the Mid-Continent region, but the origin of the forces, whether components of lateral thrust or vertical pressure, is a moot question.[1]

The conception of folding contemporaneously with sedimentation, as suggested by the writer to account for the buried hills in the Mid-Continent region, has not met with ready acceptance because of the orthodox view of folding at the close of sedimentation. Confirmation of this hypothesis by studies in a mining district are presented so succinctly by Dr. Van der Gracht that his statement is quoted:

> It becomes ever more apparent all over the world that it is *a general rule* that in *all* geosynclinal basins, folding (and resultant dip and increase of sedimentary thickness in the synclines) increases with depth. As our knowledge of the deeper strata in basins increases by deeper drilling or mining (in coal basins), this becomes ever more evident. Recently this has been worked out very carefully for the coal-bearing geosyncline of Westphalia by H. Böttcher (Glückauf, *Berg- und Huttenmännische Zeitschrift*, Essen, Germany, September 12 and 19, 1925). In the Coal Measures sequence of about 10,000 feet thickness he proves that *progressive* folding throughout the section caused *accumulation* of 63 per cent more sediment in synclinal folds than the normal thickness would call for: similarly the amount on anticlinal folds is reduced. This is exclusive of *posterior* increase and reduction of shales through the mechanism of folding or otherwise after sedimentation. This is caused by progressive folding *during* sedimentation, not through erosional unconformities during interruptions of sedimentation which are only local and accidental and increase the discrepancy. Thus, the steepness of folds increases rapidly with depth and many minor folds of considerable importance at depth do not reach the upper beds.[2]

[1] J. H. Gardner, "The Vertical Component in Local Folding," *Southwestern (Am.) Assoc. of Petroleum Geologists, Bull.*, Vol. 1 (1917), pp. 107–9; Sidney Powers, "Structural Geology of the Mid-Continent Region; a Field for Research," *Geol. Soc. Am., Bull.*, Vol. 36, 1925, with discussion by K. C. Heald.

[2] Letter to the writer, dated December 31, 1925.

Relative condensation of sedimentary rocks on and away from buried hills is considered an important factor in their reflection in younger beds,[1] but this is a self-limiting process which cannot account for renewed upwarp of the buried hill in successive periods of erosion and sedimentation as suggested by Parks.[2] The best proof that condensation forms anticlines is the fact that anticlines in Pennsylvanian strata overlie hills of "Mississippi lime" where there is no folding in the base of the lime, as shown in Figure 1 (A_2). Several such hills have been found by drilling near Tulsa, Oklahoma.

Thrust or rotational faulting has been suggested as a possible factor in the origin of some of the Oklahoma buried hills,[3] but this type of faulting is particularly well developed only in a portion of that state and buried hills are of world-wide phenomenon. Furthermore, sufficient drilling has been done on these Oklahoma buried hills to show that most of them are not faulted. Structural conditions above the faulted hills, such as in the Tonkawa, Braman Townsite, Hubbard, and Thomas fields, are similar to those above the unfaulted hills.

PERSIA

MAIDAN-I-NAFTUN

Persian oil fields have been described by Busk and Mayo[4] and by R. K. Richardson.[5] The only important field, Maidan-i-Naftun,

[1] Eliot Blackwelder, "The Origin of the Central Kansas Oil Domes," *Am. Assoc. Petroleum Geologists, Bull.*, Vol. 4 (1920), pp. 89–94; M. G. Mehl (Abstract), *Science, U.S.*, Vol. 51, 1924; V. E. Monett, "Possible Origin of Some of the Structure of the Mid-Continent Oil Field," *Ec. Geol.*, Vol. 17 (1922), pp. 194–200. A. W. Lauer in manuscript calls attention to formation of anticlines by condensation of sediments over cuesta hills and ridges. A. W. McCoy, *Southwestern (Am.) Assoc. Petroleum Geologists, Bull.*, Vol. 1 (1917), p. 110; *Am. Assoc. Petroleum Geologists, Bull.*, Vol. 5 (1921), p. 579; W. W. Rubey, "The Pershing Oil and Gas Field Osage, County, Oklahoma," *U.S. Geol. Surv., Bull.*, *751B*, 1923; H. A. Ley, *op. cit.*

[2] E. M. Parks, *op. cit.*

[3] K. C. Heald (Discussion of paper by Powers, *loc. cit.*). L. L. Foley, of Tulsa, Oklahoma, has performed experiments on the origin of folding by faulting (*Am. Assoc. Petroleum Geologists, Bull.*, Vol. 10, 1926).

[4] "Some Notes on the Geology of the Persian Oilfields." *Inst. Petroleum Technologists, Jour.*, Vol. 4 (1918), pp. 3–33.

[5] "The Geology and Oil Measures of South-West Persia," *ibid.*, Vol. 10 (1924), pp. 256–96.

is about 12 miles long and $1\frac{1}{2}$ miles wide and contains the famous $F7$ well from which almost one-third of the total Persian production to date has come. This field is in the foothills of the Iranian Mountains (Fig. 2), 17 miles from the Arabistan Plains and 140 miles north northeast of the Port of Abadan on Tigris River. Attention was first drawn to it by the presence of many seepages which yield two to three barrels of oil a day. The depth of the oil horizon varies from

FIG. 2.—Outline map showing location of Maidan-i-Naftun oil field, Persia, and Hormuz Island in the Persian Gulf.

1,000 to over 2,800 feet. No water has been found in the field. Gas occurs in large volume in the highest part of the anticline.

The stratigraphic section down to the Middle Eocene is shown in the table on page 430.

The tectonic history starts with uplift and slight erosion after the deposition of the oil-bearing, dolomitized, Asmari limestone. Its relationship with the Fars is not readily determined on the outcrop. Disconformities and overlap with a few occurrences of conglomerate have been described although conformity seems to be the rule. Similar surface relationships are found in regions where buried hills

are known underground. The cross-sections (Fig. 3) indicate a pronounced unconformity in the oil field, but the relationship of the Asmari and Fars underground is confused by flowage of the lower Fars gypsum and salt beds, and the unconformity may be merely an example of the effect of compressional stresses in beds of different

Himalayan upheaval	Third phase, last period of folding
Pliocene Bakhtiari series	Massive conglomerates, loose sands and clays; maximum thickness 15,000 feet
Himalayan upheaval	Second and major phase continued through Pliocene, rejuvenating buried hills
	Unconformity
Miocene Fars series	*Upper group.* Sandstone and red marl, a little veined gypsum. Thickness 100 to 3,000 feet
	Middle group. Sandy detrital limestone, calcareous sandstone, blue and red shale, occasional beds of gypsum. Thickness middle and upper groups varies from a few hundred feet to 2,500 feet or more
	Lower group. Bedded gypsum, intercalated red and blue shales, salt, anhydrite, secondary limestone. Thickness 5,000 feet in old desiccative basins. Exposed in Maidan-i-Naftun field
Himalayan movement	First phase initiating and locally dissecting anticlines which became buried hills
Lower Miocene	*Unconformity*
Oligocene Asmari limestone	Foraminiferal massive limestone locally replaced by gypsum or dolomite. Maximum thickness 2,000 feet
	Oil produced from eroded upper portion in Maidan-i-Naftun
Upper Eocene Spatangid shale	Petroliferous shales; interbedded limestone Thickness 250 feet

resistance. The dolomitization with attendant porosity can be interpreted as favoring the hypothesis of lack of conformity. Also, the presence of detrital limestone in the Fars indicates erosion. The anticline may be an example of refolded buried structure, but if the anticline in the Asmari limestone was pre-Fars the resistant limestone must have been a topographic hill.

The three divisions of the marine and lacustrine Fars series are conformable, but the lower Fars is contorted into folds of local

extent, and in many places is intensely folded, sheared into "fan-structures," and block-faulted. This series is exposed on the crests

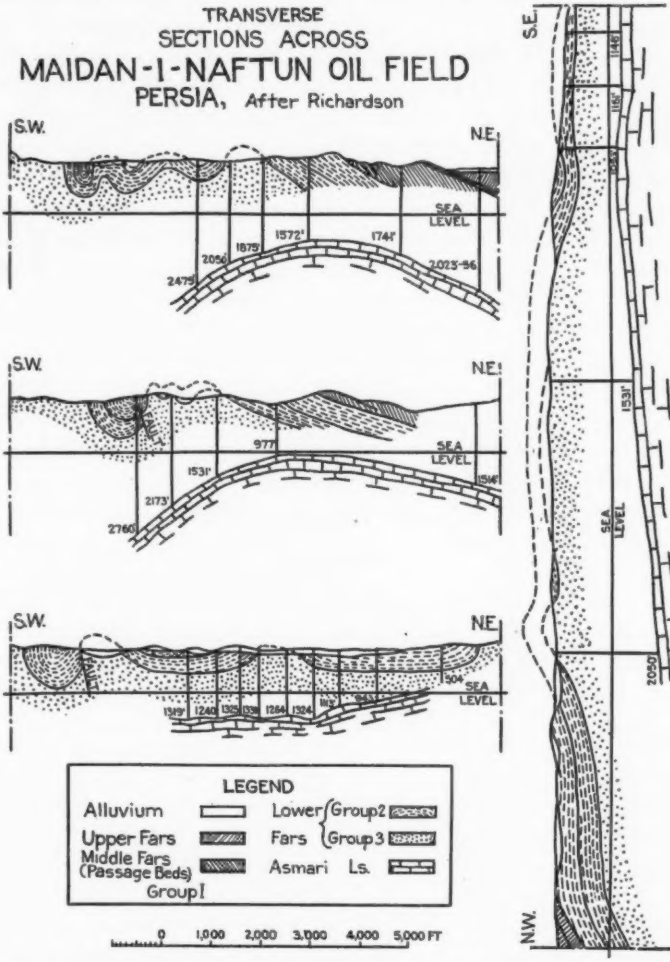


FIG. 3.—Cross-sections of Maidan-i-Naftun oil field, Persia, after Richardson. The Asmari limestone may be a buried hill under the contorted gypsum beds of the Fars series.

of the buried anticlines and the local surface structure shown in Figure 3 is not present below. Generalized cross-sections show the relation of the anticline in the Asmari limestone to that at the surface as indicated by the areal distribution of the lower Fars.

Prior to the deposition of the Bakhtiari non-marine series the anticlines now observed in the Fars series were developed with dips as high as 60 degrees. The Bakhtiari sediments filled the synclines and increased rapidly in thickness as the anticlines continued to rise and the synclines to sink. Warping had decreased in intensity when the upper group was deposited and it rests unconformably on all the older rocks. Oil was formed in the Fars before the deposition of the Bakhtiari series, because inspissated oil residues are found in the latter. The upper Bakhtiari formerly covered the anticlines.

A number of other surface anticlines in Persia have been drilled without discovering oil. If they are mapped in the Fars series they may not be reflections of deep-seated anticlines, in which case the unlocated oil reserves of Persia may be as great as they were thought to be before these dry holes were drilled. New developments at Naft Khana on the borders of Persia and Iraq indicate the discovery of another important field. Eight wells have been drilled.

KISHM ISLAND

Kishm is the largest island in the Persian Gulf near its entrance (Fig. 2). A showing of high gravity oil was found by the Anglo-Persian Oil Company in one of their wells on this island in 1924, but subsequent developments have been disappointing.

A series of domes in the upper Fars runs the length of the island and on one of them (Namakdan) the underlying Hormuz series of pre-Oligocene age crops out. In test wells on five other domes the Hormuz was found at unexpectedly shallow depths. It is interesting to note the theories advanced to account for the structural relationships: (1) two sets of earth movements at right angles, (2) salt domes, (3) laccolithic intrusions, and (4) an hypothesis of buried hills, "the somewhat unorthodox theory of Messrs. James and Halse: 'With regard to the formation of these domes—whether with Hormuz inlier exposed or not—their incipience may perhaps be accounted for by the consolidation and compression of the newly de-

posited Fars strata about eminences or bosses of older rock.' "[1] These folds on Hanjam and Hormuz islands as well as those on the Persian mainland in the region of Lingeh and Bunder Abbas[2] may be salt domes.

EGYPT[3]

Oil in Egypt was known to the Romans, but the first well, at Gebel Zeit (Jebel Zeit), Petroleus of the Romans, was not drilled until 1863 and the first well with a good showing of oil was drilled at Gemsah (Jemsa) in 1886. In both instances drilling was near a seepage and on an anticline. Commercial production began with the completion of a well at Gemsah in 1909. The second and most important discovery of oil was on the Hurghada (Rarquada) anticline in 1914. Other explorations have not yet been successful.

A columnar section of the rocks along the Egyptian side of the Gulf of Suez near the head of the Red Sea[4] is as shown on page 434.

Long anticlinal ranges with granite cores, separated by broad belts of gypsum, characterize the portion of Egypt adjacent to the Gulf of Suez (Fig. 4). The folds are generally asymmetrical with the steeper dips on the east side. There are two main ranges near the oil fields, in both of which granite is exposed at the surface. Gebel Zeit is on the southeastern end of the eastermost range. Gemsah is on a peninsula halfway between the axes of the Zeit range and the range to the west. There is evidently another lower range beneath Gemsah which does not appear at the surface. Hurghada is slightly east of a projection of the western range and the granite peak under the field is probably connected with this range.

[1] Busk and Mayo, *op. cit.*, p. 23.

[2] *Op. cit.*, p. 275.

[3] W. F. Hume, *Report on the Oilfields Region of Egypt*, Ministry of Finance, Cairo, 1916. Other information has been obtained from: *Report on the Mineral Industry of Egypt*, Cairo, 1924; "Note on the Programme . . . . of the Government . . . . with regard to the . . . . Development of the Petroleum Resources of Egypt," by E. M. Dowson, Ministry of Finance, Cairo, 1921; A. Beeby Thompson, *Oil Field Exploration and Development*, Vol. 1 (London, 1925), pp. 180, 207, who states that Hurghada is a buried hill.

[4] Columnar section modified from Hume, *op. cit.*, and W. F. Hume, "The Geology of the Egyptian Oil-field," *Inst. Petroleum Technologists, Jour.*, Vol. 7 (1921), pp. 396–98; Max Blankenhorn, "Aegypten," *Handbuch d. reg. Geol.*, Bd. 7, Heft 9 (1921), pp. 16, 57.

GEBEL ZEIT

At Gebel Zeit, Nubian sandstone and Cretaceous limestone are exposed in the hills and are covered unconformably on the plains by Miocene gypsum and by younger rocks. This anticline was prospected for sulphur and a well was drilled to a depth of 80 feet in 1863 because oil seeped out of the sulphur pits. Another well was drilled in 1866 near a seepage and was abandoned in granite at 706 feet. Several other wells have been drilled on the sea coast and east of the unroofed anticlinal buried hill and in them granite has been found at depths of 600–1,300 feet. In wells on the west side the Miocene gypsum and salt series has been found to be 2,700 feet thick.

Pliocene—Pleistocene	Pecten beds
Unconformity with rejuvenation of older folds	
Pliocene—Miocene	Oyster beds
Lower Pliocene—Miocene	Upper dolomitic reef limestone and sandstone; on hills of Gemsah, at Gebel Zeit, and Hurghada; petroliferous
Upper Middle Miocene	Gypsum and clay; at Gemsah overlain by or intercalated with limestone; carries oil at Gebel Zeit
Lower Middle Miocene	Gypsum and salt series. Forms salt beds, as at Gemsah; 2,600 feet thick on west side of Gebel Zeit
Lower Middle Miocene	Lower dolomite, coral reefs locally developed. The oil horizon at Gemsah where resting on granite. Globigerina marl, found at 2,670 feet on west side of Gebel Zeit; not present at Gemsah; found at 1,170 feet at Hurghada underlain by basal conglomerate
Major unconformity following anticlinal folding of older rocks	
Eocene	Limestones (absent at Hurghada)
Upper Cretaceous (Danian, etc.)	Limestone; at Hurghada plant-bearing pyritic sandstone underlain by Nubian sandstone and granite
Lower Upper Cretaceous (Santonian) and older	Nubian sandstone (the oil-producing horizon; also water-bearing), and other formations
Pre-Cretaceous	Granite, schist

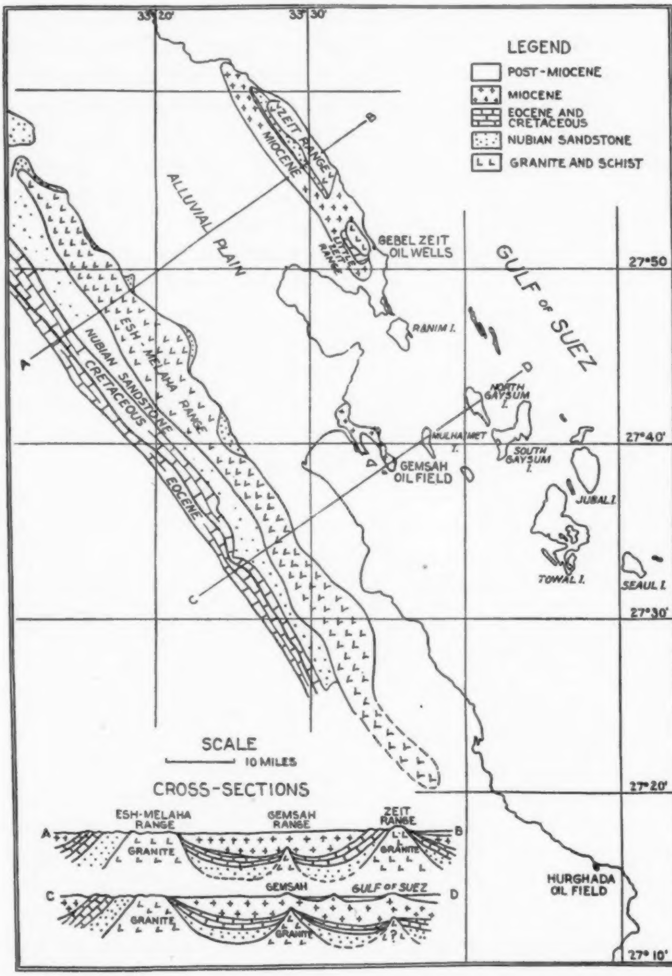


FIG. 4.—Map of a portion of Egypt bordering the Gulf of Suez showing the Zeit and Esh-Melaha ranges and the location of the Gebel Zeit oil wells and the Gemsah and Hurghada oil fields. Cross-sections indicate the relationships of ancient and now rejuvenated granite ridges to anticlinal structure (after Hume).

GEMSAH

Gemsah (Fig. 5) is 14 miles south of Gebel Zeit. Several wells were drilled here in 1886 because of seepages, two by DeBay (196 feet deep) and two by Americans. The first of the latter two showed a possible production of 25 barrels a day of 23° Baumé gravity oil, but was abandoned at 425 feet, the second was drilled to 2,120 feet with best showings of oil at 1,310 feet and from 2,000 to 2,012 feet. Two other wells were drilled to 530 and 440 feet, respectively. The first commercial oil well was completed in 1909 at a depth of 1,284 feet and produced four years. The second well was completed in 1910

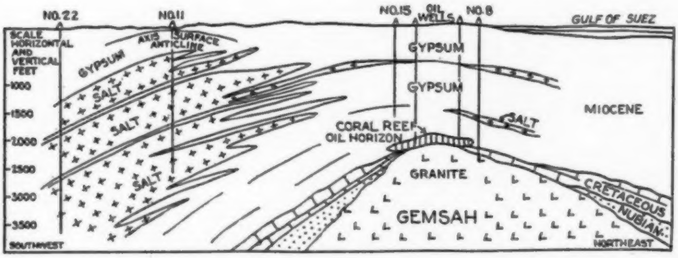


FIG. 5.—Cross-section of the Gemsah oil field, Egypt, showing the buried granite ridge surmounted by a coral reef, the oil-bearing horizon. The great thickness of salt on the southwest side may represent a salt dome.

at 1,640 feet and produced nearly 200,000 barrels in four years. A gusher flowing 20,000 barrels a day was completed in 1914 and made 340,000 barrels that year, but the entire field, in which over 25 wells have been drilled, has but four producers which yield only 230 barrels of oil daily (August 7, 1925), owing to water invading the wells. The oil is 39.5° gravity and is in marked contrast with the heavy oil of Hurghada. The depth of the producing horizon, which is a dolomitic coral reef, varies from 1,640 to 2,100 feet.

An anticline is exposed at the surface at Gemsah, but the oil is confined to a narrow belt east of the axis and along the seashore. Wells on the surface axis penetrate great thicknesses of salt with occasional beds of gypsum. In one well the salt was entered at 499 feet and the well was abandoned in it at 2,650 feet; in another the salt

was entered at 1,200 feet and was penetrated over 2,200 feet, the well being stopped in it, but in both wells beds of clay and gypsum 10–50 feet in thickness were found scattered through the salt. The other wells were drilled in gypsum with interbedded clay and thin salt beds. In the discovery oil well only limestone was reported, but the differentiation of limestone, dolomite, and gypsum by drillers is entirely unreliable. In general, the logs show that the salt beds become thinner and the dolomite beds thicker toward the east, but in no wells except the westermost have great thicknesses of salt been found. The dip is more gentle on the east than on the west side. Oil is found only in the coral reef dolomite which pinches out on the north and abuts the granite on the east, but does not have everywhere sufficient porosity to yield oil. The coral reef appears to have grown on the sides of and over the granite when the granite formed a hill in the Miocene sea. The rapid decline of wells is due to the thin, highly porous, and fissured reservoir in which oil is closely associated with water.

Various hypotheses have been advanced to account for the remarkably different sections in nearby well logs with a sharp granite ridge striking out into the sea and not exactly parallel with the axis of the surface anticline. One hypothesis is that the sale on the west side of the granite represents a salt dome.[1] This hypothesis is supported by the two salt wells and by the limestone in several wells which has been compared to cap rock of salt domes.

The presence of the stratified clay beds in the salt and the corals in the producing dolomite do not favor the salt-dome hypothesis. Surface anticlines where underlain by salt or gypsum beds are unreliable and lack of superposition of the surface on subsurface anticlines may not have any significance. Thinning of the salt to the east indicates a lenticular condition. Finally, the thick salt beds may be steeply tilted with no evidence of this tilting at the surface. Steep dips are common in all of these anticlinal axes and according to

[1] Hume "considers the salt aggregates to have accumulated in the (salt-cored) domes as a consequence of the initiation of dome structure and not to be primary causes of doming." (Busk and Mayo, *op. cit.*, p. 23.) A. Beeby Thompson, *op. cit.*, p. 207, states that, "Nothing in Egypt is suggestive of salt dome conditions."

Hume and Mrazec[1] they owe their present form to overfolding and diapirism.

Several other anticlines with salt beds or possible salt domes are known in this region. Two anticlinal islands off Gemsah, Mulhaimet (Um el Heimet), and Jubal, have been drilled and granite or granitic sands encountered at about 1,500 feet, but an intermediate anticlinal island, Gaysum, is underlain by shale and gypsum to a depth of over 2,600 feet.

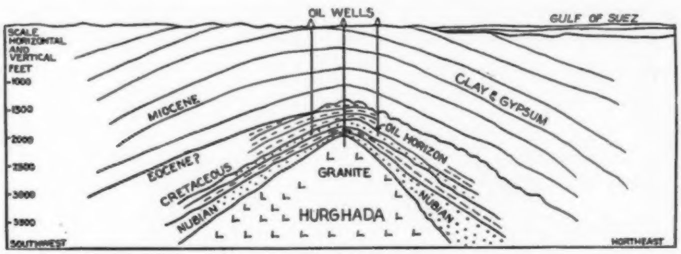


FIG. 6.—Cross-section of the Hurghada oil field, Egypt, showing the buried ridge and overlying anticline.

The widespread intercalated salt and gypsum beds without concentration of the salt in pure bodies and the presence of granite or of granitic sand forming the cores of anticlines favor the hypothesis of refolded buried hills rather than that of salt domes or even salt domes on the sides of buried hills to account for the origin of the folding.

HURGHADA

Hurghada (Fig. 6), located 31 miles southeast of Gemsah, is a deeply buried granite ridge, the upper dolomitic limestone cropping out at the surface. It was discovered because Hume in 1911 found an oil-smelling limestone at the surface. There are reported to be two parallel surface anticlines, but oil has been found only in the western one. Wells penetrate the Miocene with normal thickness of the gypsum-salt series, but no thick salt beds are found as at Gemsah.

[1] Overfolding, which leads to overthrusting and diapirism, takes place as follows, according to Hume (*op. cit.*, 1916, p. 61): "If the lower strata thus highly inclined are of a massive nature; there is a differential movement between them and the softer beds above them which causes them to appear as though intrusive through the overlying formations."

The basal unconformity is reached at about 1,500 feet. The Eocene is not present and oil comes from Upper Cretaceous sandy shale, the Nubian sandstone, and the brecciated and weathered surface of the granite at a depth of about 1,670 feet. Records of wells which have been drilled into the granite core indicate a structural conformity of the pre-Miocene rocks, but a lack of exact superposition of the anticlinal axes in the Miocene on those in the older rocks, as is typical of reflected buried hills. Steepness of dip increases with depth. That in the Miocene ranges from 10 to 20 degrees. The fold is asymmetrical, the steeper dip being on the east side. A little Nubian sandstone containing coarse sand grains and white quartz pebbles covers the granite.

Hurghada is the principal oil field of Egypt. The first well had an initial production of 9,000 barrels a day and the field now (August, 1925) produces about 23,800 barrels a day of 22.5° gravity oil from 30 wells.

Gebel Zeit is an excellent example of an unroofed buried hill. Gemsah and Hurghada seem to be good examples of buried hills with granitic cores and asymmetrical dips on the flanks of these eroded granite ridges. Two periods of folding have given rise to the steep dips underground and the gentle dips near the surface. The lack of accurate recognition of the subsurface folds at the surface is due to the salt and gypsum series, the folding of which does not give reliable indication of underlying structure.

MEXICO[1]

One of the best-known examples of buried hills is the "Tamasopo" Ridge under the southern oil fields (the "Golden Lane") of Mexico which has been explored from Tamiahua Lagoon, near Dos Bocos, on the north, past Tuxpam River at Alamo, on the south, a distance of about 50 miles. The limestone of the "Tamasopo" Ridge, now called El Abra, because it is of Lower Cretaceous age whereas the Tamasopo limestone in Tamasopo Canyon is Upper

[1] Description of the Tamasopo Ridge was made possible by information furnished very kindly by Walt M. Small, Paul Weaver, Earl A. Trager, D. R. Semmes, and F. A. Herold. The writer is especially indebted to Mr. Small for the latest interpretations of geologic history, for several cross-sections, one of which is reproduced, and for revision of the manuscript.

Cretaceous, forms a buried ridge or scarp for most of its length with a steep west flank and gentle east slope (Fig. 7), best explained as a continental fracture comparable to the Nemaha Mountains (Granite Ridge) of Kansas. The ridge or escarpment is a faulted anticline in certain areas between Cerro Azul and Alamo and has a steep east flank and double faulted crest at Cerro Viejo and possibly also at Tierra Blanca, but for most of its length it is a simple fault scarp as shown in a typical cross-section, Figure 8.

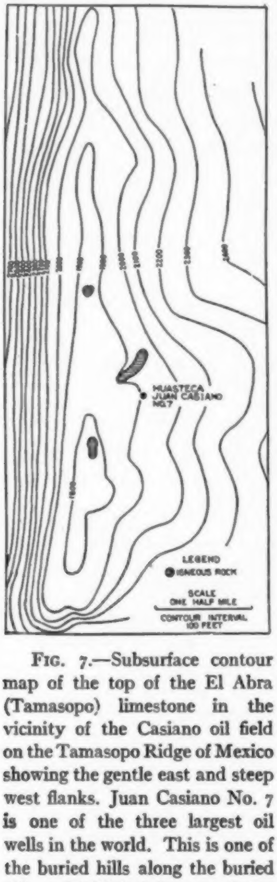


FIG. 7.—Subsurface contour map of the top of the El Abra (Tamasopo) limestone in the vicinity of the Casiano oil field on the Tamasopo Ridge of Mexico showing the gentle east and steep west flanks. Juan Casiano No. 7 is one of the three largest oil wells in the world. This is one of the buried hills along the buried ridge. (Published by permission of E. DeGolyer.)

The following geologic section as interpreted by geologists at Tampico is given to indicate geologic history. The Idolo Island section is that published by Dumble and Applin. Formation thicknesses are to be considered as tentative, not definite. The Alazan shale has been reclassified and the formation is now restricted to the shale of Oligocene age. The Chicontepec occurs in the area several miles west of the ridge.

The known geologic history commences with a pre-Jurassic basin. After Jurassic sedimentation, the El Abra lime stone was deposited to a thickness of over 2,500 feet. The surface of this limestone was eroded and rendered cavernous and the oil production comes from this eroded portion. It has been found that the El Abra limestone and the Tamaulipas limestone of Panuco are both of Washita age.

The fracturing and folding of the ridge was initiated either before or after San Felipe deposition, but the relief was so low that the Mendez formation and possibly also the Valasco are represented by

thin sections over much of the ridge. Later erosion also reduced their thickness. The buried hills along the ridge, as shown in Figure 7, were hills (probably all anticlines)—sometimes above and sometimes below water during Upper Cretaceous sedimentation. The main up-

FIG. 8.—Cross-section of the Cerro Azul oil field, Mexico. The dip of the fault plane and the relative thickness of formations on the west side are generalized to illustrate geologic conditions inferred from studies of well logs and well cuttings. The Chicontepec is confined to the area west of this section and is shown here merely to make the section complete. (Reproduced through the kindness of Walt M. Small.)

lift accompanied by extensive erosion was at the close of this period. During the Eocene the ridge was alternately submerged and reelevated, but only remnants of the Eocene were preserved on it. Renewed folding after the Oligocene gave rise to the structure ob-

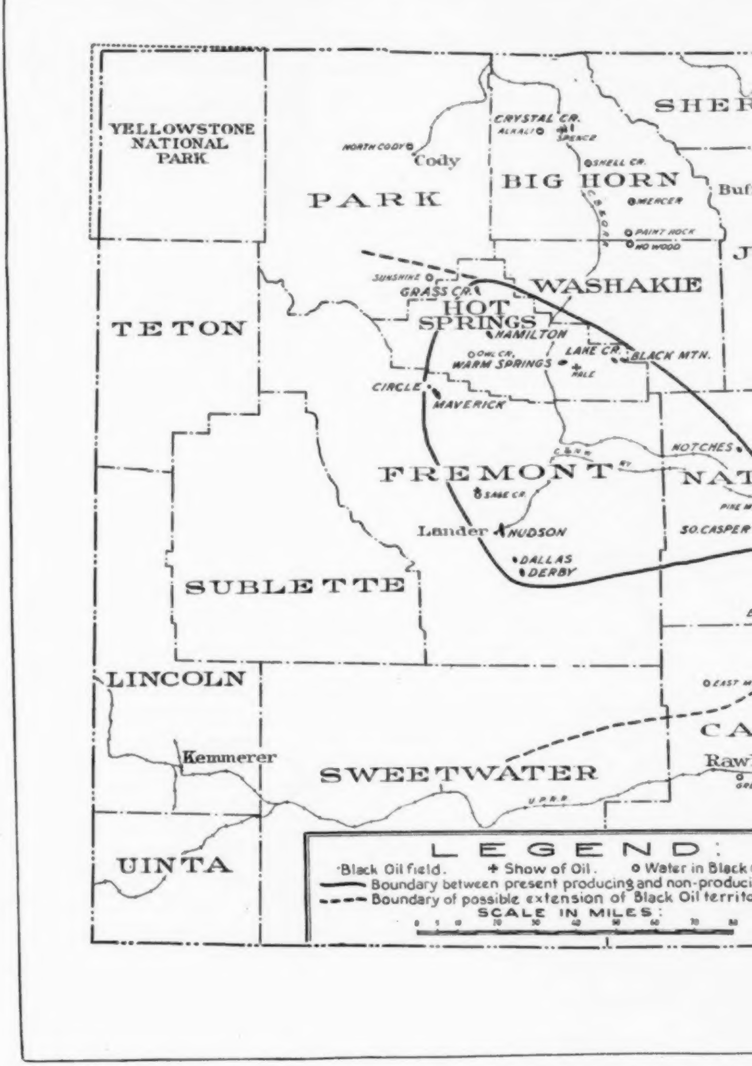
served at the surface in which the ridge is very faintly reflected as a line of anticlines.

Thickness of sedimentary rocks on either side of the ridge relative to that on the axis proves it was a topographic feature at least twice

Age	Formation	Thickness, Feet		
		West of Ridge	Above Ridge	East of Ridge (Idolo Island)
Pleistocene and Recent	Gravel, etc.			
Miocene	Tuxpam	absent	absent	0–200 (?)
Major period of folding, producing structure observed in surface outcrops; intrusion of basalt; erosion				
Oligocene	San Rafael, Meson	0–1,500	absent except locally	1,000 (?)
Disconformity	Alazan	2,000	1,800–2,000	1,200 (?)
Uplift of ridge and erosion				
Eocene	Guayabal	500?	0–100(?)	
	Tantoyuca	500	absent (?)	950
Disconformity	Temporal shale		absent (?)	
	Chicontepec	2,000 (farther west)	absent	700 (?)
Major uplift, folding and faulting; erosion of Cretaceous shale				
Upper Cretaceous				
Valasco (Tamesi)		1,100	occurs locally	500 (?)
Mendez (Papagallos)		1,500	occurs locally	100
Initial (?) uplift of ridge by folding and faulting with downwarping of basin on the west				
San Felipe		800–1,000	50–100 locally absent	150
Unfoncormity; erosion of Tamaulipas if originally present; fracturing of ridge (?)				
Lower Cretaceous (Washita) Tamaulipas limestone		?	absent	0–100
El Abra limestone		Thickness unknown	Oil-bearing horizon; over 3,500 feet thick	(Found at 4,666 feet at Idolo Island)
Unconformity				
Jurassic				

in geologic history and is therefore a buried ridge throughout its extent even though portions of it represent buried structure.

Panuco may furnish other examples of buried hills, but the structure of the Panuco fields does not show them as clearly as does that of the southern fields ridge, and Panuco is, therefore, not described. The Panuco uplift is the extension of the Tamaulipas Mountain uplift and in consequence is overlain by a thinner Tertiary section than the southern fields ridge.



MAP SHOWING LOCATION OF BLACK OIL

BLACK OIL FIELDS IN WYOMING

OCCURRENCE OF BLACK OIL IN WYOMING[1]

JOHN G. BARTRAM
Casper, Wyoming

ABSTRACT

The black oil fields of Wyoming, which produce from the Embar and Tensleep formations of Permian-Pennsylvanian age, have been found only in a limited area in the west-central part of the state. Within this area most favorable anticlines are productive, and outside of it nothing commercial has been found on the many anticlines drilled. This condition is best explained by the character of the Embar formation, which is apparently the source of the oil. In the productive area, it is composed of marine limestones and limey shales, and in the barren areas of red beds and other flood-plain deposits. The limiting line of productive territory may be extended somewhat in the future, especially to the south and west. If good source rocks exist in other Paleozoic formations elsewhere in Wyoming, other black oil fields may be developed outside the present restricted area.

INTRODUCTION

The Wyoming fields produce two different and distinct grades of oil that are known, respectively, as light oil and black oil. The light oil, which is the most important, comes from the Cretaceous formations and has a paraffin base with minor amounts of asphalt. It comprises more than 98 per cent of the state's present production. The black oil, which comes mostly from the Embar and Tensleep formations of Permian-Pennsylvanian age, has an asphalt base, and is a heavy oil with an average gravity of about 22 degrees Baumé, and a gravity range from 15 to 32 degrees. It is used for fuel and for the manufacture of asphalt. Because of the small demand and low price, the production of black oil is low, not over 1,500 barrels a day, but much more could be produced under favorable conditions, inasmuch as several fields are wholly or partly shut in, and most of them are relatively undeveloped.

LOCATION OF FIELDS

Although commercial fields of light Cretaceous oil have been discovered in nearly every part of Wyoming, commercial fields of black oil have been found only in a limited area in the west-central part of the state (Plate 13). This area is roughly a large triangle,

[1] Published by permission of the Chief Geologist, Midwest Refining Company.

whose borders extend from the Grass Creek field on the northwest, eastward to the Notches, South Casper Creek, and Bolton Creek fields, which are west and southwest of Casper, then westward to Derby Dome, which is south of Lander, and northward in a slightly curved line to Grass Creek again. Within this area all the black oil fields of commercial importance in Wyoming are located, and almost none of the structurally favorable anticlines have been failures. Outside of this area, there are no commercial black oil fields, and many promising anticlines have yielded only water when drilled.

SOURCE OF OIL

This occurrence of black oil in one area, and its absence in the remainder of the state, is best explained by the character of the Embar formation, which is composed of marine limestone and calcareous shale in the productive area, and of red beds and flood plain deposits in the barren areas. In the Wind River and Owl Creek mountains, near the best black oil fields, the Embar formation consists of 200 to 350 feet of limestone and calcareous shale, rich in fossils and organic material, and containing one or more phosphate beds. The limestone and shale appear to be good primary oil horizons and the oil formed in them has accumulated on favorable anticlines in the underlying Tensleep sandstone and in irregular porous layers in the Embar limestone itself. In the old Dallas field, the most prolific oil horizons seem to coincide nearly with the phosphate beds in the Embar.

To the north, east, and south of this area of marine beds and also of oil production, the limestones grade abruptly into red beds that were deposited on flood plains. These red beds contain few traces of organic material, and appear to be very poor source rocks for oil. No commercial black oil has been found where they are present. The line that limits the area of thick limestones and marks their change to red beds apparently coincides nearly with the line already drawn to separate productive and non-productive territory except on the south where possible black oil structures are still untested in the Lost Soldier district. This line is really the shoreline of an arm or bay of the Embar sea that extended into Wyoming from the main Embar sea. This main sea was located farther west, for the

limestone phase of the Embar thickens in that direction and extends over a large area, and the fossils in it are reported to be mostly of Pacific types. The bay in central Wyoming was bounded on the north, east, and south by flood plains, on which sandstone, sandy shale, red and vari-colored shale, and gypsum were deposited. The material for these sediments was derived from land masses to the north and south.

This change of the marine limestones to red beds has been recognized by several geologists, in particular by Condit[1] who has described the character of the Embar formation in northern Wyoming, and by Knight[2] who has studied it in detail in the Laramie Basin and in the southern part of the state. Condit has published two sections, which show the change in conditions of sedimentation. Another section (Fig. 1) has been drawn to show the change from the central part of the state toward the southeast. With some additional study of the Embar and other Pennsylvanian formations, it should be possible to draw accurate boundaries between the marine and non-marine phases of the formation in all parts of the state, and thus determine the area in which black oil may be found and that in which it is practically useless to prospect for it.

The limiting line of productive territory may be extended somewhat in the future and is not meant to condemn all anticlines outside of it. In particular, it may extend south to include the anticlines of the Lost Soldier district, none of which have been properly tested in the Tensleep. There are good limestones and other marine beds in the Embar formation on the Rawlins Hills and one bed of limestone is heavily saturated with oil on the outcrop.

The productive territory may also extend a little farther north or east. It can cover a large area farther to the west, if favorable anticlines to trap the oil are discovered, inasmuch as the marine beds are thick in that direction.

Elsewhere in the Rocky Mountains some black oil has been found that originated in formations other than the typical Embar. Oil in the Soap Creek field, Montana, probably originated in the Amsden

[1] D. D. Condit, "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geological Survey Prof. Paper 98-o*, 1916.

[2] S. H. Knight. Personal Communication.

or Madison formation. If good source rocks can be discovered in the Paleozoic formations in other parts of the Rocky Mountains, other

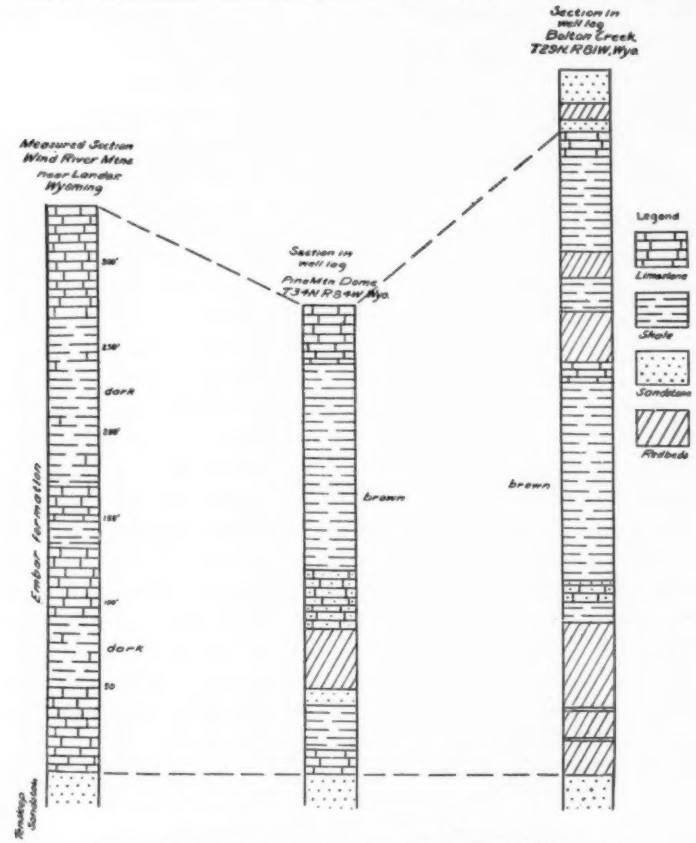


FIG. 1.—Sections of the Embar Formation in Central Wyoming

important black oil fields may be found. The remaining area is not necessarily condemned because it is outside of the rich Embar district.

BLACK OIL DEVELOPMENT

The accompanying map (Fig. 1) shows the anticlines that have produced enough black oil to be considered commercial fields. They

are: in the southern part of the Big Horn Basin, the Grass Creek, Hamilton, Warm Springs, Black Mountain and Lake Creek anticlines; in the Wind River, or Lander country, the Maverick Springs, Circle Ridge, Hudson or Lander, Dallas, and Derby anticlines; and in that part of the Powder River Basin west of Casper, the Notches and South Casper Creek anticlines, with perhaps the Bolton Creek anticline included. These are all within the area designated as possible producing territory. A few other anticlines in this area have not produced oil in the Embar or Tensleep, but their failure can be explained by excessive faulting and water flushing.

South and southeast of the productive area, no black oil has been found, though the Lost Soldier district is still untested. The failures include, in the area east of Rawlins, the Grenville dome; and in the Laramie Basin, the McGill, Flat Top, West Foote Creek, and Como Ridge anticlines.

In the east-central part of Wyoming, a little oil associated with much water has been found on North Casper Creek anticline, which is close to the boundary between productive and non-productive territory, but the Bates Hole, Bodie, Emigrant Gap, and Tisdale anticlines all carried water. Farther east and northeast, the Colony, Moorcroft, Upton, and LaBonte or Phillips anticlines all showed water. A test well on the Old Woman anticline, east of the Lance Creek field, made one short flow of oil and turned to water.

In the eastern and northern part of the Big Horn Basin, a little black oil has been found on Crystal Creek and Spence anticlines, but none of the wells are large enough for profitable production, even at a shallow depth. The Nowood, Paintrock, Mercer, Shell Creek, Sunshine, and North Cody anticlines in the same area have produced water. Northeast of the Big Horn Basin, in Montana, one anticline, Soap Creek, has produced black oil, and it may be that in the northeastern part of the Big Horn Basin conditions are somewhat favorable for black oil.

In western Wyoming, west of the fields near Lander, no wells have been drilled to black oil horizons, principally because almost no favorable anticlines are known. Directly west of Lander is the large mountain uplift of the Wind River range, and beyond that the Tertiary-filled Green River Basin, on the east side of which the

Tertiary formations overlap all other formations down to the basal granite. At the extreme western edge of the state, the country is mountainous and the rocks have been so intensely folded and faulted, that few if any anticlines exist which have dips low enough, and which are properly closed and shaped, for oil accumulation. Favorable anticlines may be found in that district, and theoretically, black oil should be found in them, since marine Pennsylvanian beds in considerable thickness are present.

GEOLOGICAL NOTES

OIL FIELDS OF CHINA: ACKNOWLEDGMENTS AND CORRELATIONS

The undersigned take pleasure in acknowledging the courteous correction by Mr. T. O. Chu of the unintentional omission of credit for material used in his paper on the Oil Fields of China, Vol. 8, pages 169–77 of this *Bulletin*. The circumstances are somewhat unusual in that, while the Chinese Government paid half of the expenses of the China explorations, the writers were employed solely by the co-operating American company and reported to it alone. Their reports, on the abandonment of the investigations, were given to the Chinese Government, and on the organization of the Geological Survey of China in 1920 came into the possession of that Bureau, of which Mr. Chu was a member. The cross-section in the paper cited and practically all geological data as well as that pertaining to oil wells in Shensi appear to have been taken from these reports. Wells 1 to 4, marked C. B. M. in Mr. Chu's table and said to "have been sunk in this field by the Chinese Bureau of Mines," were in reality drilled under the direction of the provincial government of Shensi and the Shensi Oil Company several years before the organization of the Bureau of Mines.

The Geological Survey is to be congratulated on the age determinations of certain formations above the Shensi series as set forth in the second note of Mr. Chu (*ibid.*, Vol. 9, pp. 1295–98), the most important of which is that establishing the oil-bearing Shensi series as Jurassic instead of Permian.

FREDERICK G. CLAPP
MYRON L. FULLER

ANNUAL MEETING OF THE CORDILLERAN BRANCH OF THE GEOLOGICAL SOCIETY OF AMERICA

The program of the annual meeting of the Cordilleran Section of the Geological Society of America, which was held at Stanford University, California, January 28 and 29, 1926, was of extraordinary interest to

petroleum geologists for fully a third of the time was devoted to a symposium on "Siliceous Shale and the Origin of Petroleum in California."

This symposium, organized and led by Professor C. F. Tolman, began with a discussion by Dr. Becking and Dr. McMillan of "Life History and Chemical Reactions after Death of Freshwater and Marine Diatoms." The genetic significance of the fossil fish and the fossil birds that have been found in the siliceous shale was dealt with by Dr. David Starr Jordan and Dr. L. H. Miller, respectively. The significance of the known occurrence of arkose interbedded with diatomaceous shale and of the presence of phosphate bands in the Monterey shale was pointed out by H. G. Schenck and R. D. Reed, respectively.

A description of the siliceous shale of the Santa Maria Basin by B. F. Hake furnished a good introduction for a paper by G. C. Gester on the relation of the siliceous shale of California to the oil deposits, one by Robert Anderson, who presented the reasons for believing diatomaceous and foraminiferal shales the sources of California oil, and a historical review of the theories that have linked the diatomaceous shale to the oil fields, by Frank M. Anderson.

The symposium was closed by C. F. Tolman who summarized the progress of microscopic study of the siliceous shale formations.

The general impression left by the symposium was that those who participated in it are for the most part quite convinced that California oil comes from the diatomaceous and foraminiferal shale, and that there is some tendency to cling to the idea that the asphaltic oils come from the diatomaceous and the paraffin base oils from the foraminiferal material. The evidence showed quite clearly that the siliceous shale accumulated close to shore in some instances, and in lagoons or landlocked bays in many instances. There is still room for argument regarding the relations between the shale and the oil pools, since the evidence that has been relied on to establish the diatomaceous origin of California oils is for the most part circumstantial—the coincidence between diatomaceous strata and the major oil pools.

An interesting suggestion relating to the origin of the diatomaceous shale was made by Hoyt S. Gale, who pointed out the existence of volcanic material associated with the formations that are rich in diatoms, indicating a possible source of silica for the diatom tests, with silica-rich waters furnishing a habitat in which the diatoms could thrive. Consumption of the soluble silica by multiplication of the diatoms would terminate the cycle of great diatom development.

K. C. Heald

NEW ZEALAND OIL DISCOVERY

In the drilling of a well for oil at New Plymouth, New Zealand, an amount of gas in excess of 5,000,000 cubic feet per day was found at a depth of 1,555 feet with a rock pressure of 625 pounds per square inch. This well was only about 1,000 feet distant from a mass of andesite-porphyry several hundred feet in extent. The gas sprayed several barrels of oil per day. It analyzed 78 per cent carbon dioxide, the balance being methane and ethane.

The writer is interested to know other localities in which large percentages and volumes of carbon dioxide have been found under pressure, and their relation to igneous occurrences and known oil fields.

FREDERICK G. CLAPP

REVIEWS AND NEW PUBLICATIONS

Oil Shale. By RALPH H. MCKEE. "American Chemical Society Monograph Series," The Chemical Catalog Company, Inc., New York, 1925. Pp. 326, Figs. 35.

This book contains thirteen chapters contributed by different authors as follows: (1) "Shale Oil, A General View of the Industry," by Ralph H. McKee; (2) "Origin of Oil Shale," by R. D. George; (3) "Geology and Distribution of Oil Shale," by R. D. George and S. C. Ells; (4) "Kerogen, The Oil-Yielding Material of Oil Shale," by Ralph H. McKee; (5) "Fundamental Factors in Analyzing and Evaluating Oil Shale," by Lewis C. Karrick; (6) "The Refining of Shale Oils," by E. E. Lyder; (7) "Nitrogen Constituents of Shale Oil," by Ralph H. McKee; (8) "Economic Considerations of the Oil Shale Industry," by W. A. Hamor; (9) "Basic Factors of the Shale Oil Industry," by M. J. Gavin; (10) "American Experimental Oil Shale Distillation Plants," by W. A. Hamor; (11) "Abstracts of Shale Oil Articles," by R. H. McKee and E. E. Lyder; (12) "Patents in Shale Oil Field," by R. H. McKee.

The book is largely a compilation of data and information already published by the various authors elsewhere with the exception of the last three chapters. Chapter ix largely repeats chapter i, and it seems that this space could have been used to better advantage by the inclusion of additional technical data. Chapters x and xii contain many data which are published for the first time. This will undoubtedly be of much value to those interested in plant construction and operation.

A review of this book would be incomplete without special mention of the valuable chapter giving the abstracts of 1,120 different articles which have been published on oil shale.

Oil Shale is authoritative and as a whole presents in summary the results of a great amount of scientific work done in the past six years by the authors. It is a valuable addition to the library of anyone interested in oil shale.

JOHN R. REEVES

OIL HILL, KANSAS

THE ASSOCIATION ROUND TABLE

THE GEOLOGICAL SOCIETY OF AMERICA

The Geological Society of America extends a cordial invitation to the members of the American Association of Petroleum Geologists to attend the sessions and take part in the various other functions of the Thirty-ninth Annual Meeting, to be held at Madison, Wisconsin, under the auspices of the University of Wisconsin and the State Geological and Natural History Survey, December 27–29, 1926. We are assured by the Local Committee that acceptance of this invitation would be especially agreeable to them, and that accommodations are adequate.

It would be of distinct advantage in making local arrangements if those who expect to attend would notify the Secretary of the Geological Society.

CHARLES P. BERKEY, *Secretary*

COLUMBIA UNIVERSITY
January 20, 1926

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

C. C. Robbins, Ralph E. Davis, and Eugene A. Stephenson, of Pittsburgh, Pennsylvania, were recent visitors in Shreveport, Louisiana.

Howard N. Spofford, Box 1836, El Dorado, Arkansas, was in Central America in April in the interest of clients.

Max W. Ball, 1104 First National Bank building, Denver, Colorado, visited Shreveport, Louisiana, last March while on an inspection trip of East Texas producing areas.

Louis A. Barton, of Shreveport, Louisiana, won second place with a net score of 75 in the golf tournament of the Association held at the Dallas convention last March. Major Barton was presented with a steel-shafted driver.

L. W. Stephenson and C. H. Dane, of the U. S. Geological Survey, Washington, D.C., spent about three weeks in southwestern Arkansas and northeastern Texas in April, reviewing the stratigraphy of the area in preparation of a government report.

K. B. Nowels, of the U. S. Bureau of Mines, has recently been transferred from Dallas to the Petroleum Station of the Bureau at Laramie, Wyoming, where he is to be engineer-in-charge.

A daughter, Patricia Evelyn, was born to Dr. and Mrs. Henry V. Howe, Baton Rouge, Louisiana, March 11, 1926. Dr. Howe is head of the department of geology at Louisiana State University.

M. C. Israelsky, formerly with the Humble Oil and Refining Company at Houston, Texas, is now paleontologist on the geological staff of the Standard Oil Company of Louisiana at Shreveport.

W. E. Hopper, consulting geologist, Shreveport, Louisiana, recently returned from a trip through Colorado, Utah, and Wyoming.

B. W. Blanpied, geologist for the Gulf Refining Company in the Mississippi district, visited the Shreveport, Louisiana, office in March.

J. L. Henning, formerly of the Union Sulphur Company of Lake Charles, Louisiana, was a recent visitor in Shreveport.

J. E. Eaton has recently completed nearly two years of geological mapping in California for the Milham Exploration Company, a subsidiary of the Mexican Seaboard Company. He is now resuming general consulting work with offices at Suite 628, Petroleum Securities Building, Los Angeles.

W. T. THOM, JR. has been giving a brief course of lectures on petroleum and coal geology at Princeton University during the spring term.

FRED B. ELY left New York in March to spend a year in Venezuela, with headquarters in Maracaibo.

CHARLES E. SCHUCHERT, of Yale University, gave several popular lectures on geology March 18, 19, and 20 at the Texas Agricultural and Mechanical College, College Station, Texas. Following these lectures he attended the annual meeting of the Association at Dallas.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICERS FOR 1926-1927

E. DE GOLYER, *Retiring President*
65 Broadway, New York

ALEX W. McCOY, *President*
Denver, Colorado

C. R. McCOLLOM, *Vice-President*
Los Angeles, California

JOHN L. RICH, *Editor*
Ottawa, Kansas

FRITZ L. AURIN, *Secretary-Treasurer*
Ponca City, Oklahoma

REGIONAL DIRECTORS

Eastern:
ROSWELL H. JOHNSON, University of Pittsburgh, Pittsburgh, Pennsylvania.

North Mid-Continent:
W. B. WILSON, Box 2044, Tulsa, Oklahoma.

South Mid-Continent:
R. B. WHITEHEAD, 702 Magnolia Building, Dallas, Texas.

Arkansas-Louisiana:
A. F. CRIDER, 821 Ontario St., Shreveport, Louisiana.

Gulf Coast:
DAVID DONOGHUE, West Building, Houston, Texas.

Rocky Mountain:
THOMAS S. HARRISON, 1106 First National Bank Building, Denver, Colorado.

Pacific Coast:
STEPHEN H. GESTER, 607 Standard Oil Building, San Francisco, California.

Mexico:
WALTER M. SMALL, Apartado 76, Tempico, Mexico.

Venezuela:
FRED H. KAY, Apartado 1, Caracas, Venezuela.

THE PACIFIC SECTION

OFFICERS

E. F. DAVIS, *Chairman*
401 Higgins Building, 2nd and Main Streets, Los Angeles, California

C. M. WAGNER, *Secretary-Treasurer*
Care of General Petroleum Corporation, Higgins Building, 2nd and Main Streets, Los Angeles, California

MEMBERSHIP

Membership in the Pacific Section is restricted to members of the A.A.P.G. in good standing, residing in the Pacific Coast States. Dues of $2.00 per year are payable to the Secretary-Treasurer of the Pacific Coast Section. Members of the A.A.P.G. transferring to the Pacific Coast are cordially invited to become affiliated with the local section, and to communicate their change of address promptly to the Secretary-Treasurer of the Pacific Section.